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ABSTRACT

Sixty-eight specific interventions to improve science education were grouped into 11 categories. Each category was then related to one of three major intervention objectives and an associated group. These categories, grouped by objectives are: (1) interventions increasing amount of time students are engaged in learning science (increasing student requirements); (2) interventions increasing quality of instruction (preservice education; enhancing teaching as a career; improving instructional practice; inservice education; improvement of materials, facilities, and equipment; and assistance from business and industry); (3) interventions to increase the "match" between actual classroom objectives with objectives most appropriate in today's world; and (4) facilitating interventions (improving local leadership, testing programs, and public education). Analyses were conducted to determine the cost of implementing each intervention and to determine a rating of its effectiveness based on research data and other available information. The major conclusion reported is that solutions to problems in science education must be sought in the form of combinations of interventions with full regard for the interactions among these interventions. (Also included are modifications of analyses as they pertain to mathematics education and a delphi study on interventions for improving science and mathematics education in Colorado.) (JN)

IMPROVING SCIENCE AND MATHEMATICS EDUCATION: COSTS AND EFFECTIVENESS

January 1984

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PREFACE

This project was born about a year ago in a climate of uncertainty about the state of science and mathematics education in the United States. The frequent references to a "crisis in science education" may have been a bit of hyperbole, but one can find little basis for rejecting the concern about declining test scores, lack of attention to improving the curriculum, low student interest in science and mathematics, and shortages of well-trained teachers. During the past year, public concern rose as our apparent downward slide in the economic competition with other countries increasingly was perceived to be an outgrowth of inadequate education, and as a seemingly unending number of reports issued from various committees, task forces, and commissions about U.S. education.

Given these events, it is not surprising that there should be a sharp rise in public expressions of concern about education, and especially science and mathematics education. This public concern, in turn, has led to much political activity. Many new bills providing new funding for science and mathematics education have been presented for debate in the U.S. Senate and House of Representatives. In contrast to the Sputnik era of a quarter century ago when responses to similar concerns were mainly at the federal level, extensive activity now is occurring at the state level. Legislation is being considered and passed, task forces and commissions are deliberating (often at the behest of governors), and assistance is being offered to local school districts considering such actions as increases in graduation requirements. Literally dozens of different actions for improving science and mathematics education are being considered by various political groups from the local to the national level.

Within this climate of urgency for action, there is also considerable uncertainty about which of the many proposed interventions will "produce the most bang for the buck," or for that matter, produce any "bang" at all. Fortunately, there are steps that can be taken to systematically and logically analyze the situation based on estimates of the costs involved and research findings about the potential success of various actions to produce educational change. The project described in this report was initiated to produce just such an analysis. The techniques used for the analysis deserve considerable explanation in and of themselves, but for that information the reader is referred to Chapter 1 of this report.

Additional information about the format of this report, however, is appropriate here. The bulk of the report, Part 1, is focused upon science education, while Part 2 is quite short and addresses mathematics education. The project was originally conceived as a science education study drawing upon the extensive work done by the first author in integrating the results of nearly eight hundred science education research studies. Because of the interest of the agency sponsoring this project, the Colorado Department of Education, mathematics was added even though it was recognized that the project personnel did not have the same existing intimate knowledge of the research in that area. Fortunately, the nature of the analysis designed for science education has many facets that overlap substantially with what would be done in doing a comparable analysis for mathematics education. Because several points in the analysis are subject specific, i.e., focused upon the particular subject matter of science, it was decided to conduct the analysis in detail for science and then add information on mathematics at several particularly key points. The report format that evolved from this process is apparent from reviewing the Table of Contents. Specifically, the analysis for science education is in Part 1. The following section, Part 2, explains ways in which the project results can be safely extrapolated to mathematics and cases in which some different conclusions may be appropriate because of the subject specific aspect of the work.

Finally, it should be noted that Part 3 is as much an appendix to the report as anything else. It reports the results of a Delphi study using a series of questionnaires sent to a group of leading educators in Colorado to gain their judgments as to the effectiveness and feasibility of interventions for improving science and mathematics education and the appropriateness of various instructional goals for science and mathematics. It is of interest as a separate report and was used as a source of information for writing the first two parts of this report.

As a result of this report organization, some readers may choose to read only Part 1 and obtain the information of interest to them, i.e., information about science education. The person interested in mathematics education will need to read both Parts 1 and 2 to receive the full scope of the report. Still other readers may have sufficient interest in the results of the Delphi study that they would choose to read Part 3 as well.

As with most projects of this scope, it was the work of more than one person and the various roles should be acknowledged here. First of all, Cynthia DeLarber has played a key role. A staff member of the Colorado Department of Education, she has served as a liaison with that agency. (The Department has provided the majority of the project's financial support; the remainder of the support came from the University of Colorado.) Her role has been more than a liaison, however, in that she has been involved in the actual project work. As a policy analyst, she was well prepared to obtain needed information from a variety of sources. In addition, she played the key role in obtaining and analyzing information acquired via the Delphi study. Her work has been handled with competence and dispatch. William R. Munsell served as a graduate research assistant on this project during the Fall 1983 and was particularly instrumental in collecting and processing the information for the cost analyses used in this report.

Additional participants in the project were an advisory group of nine people who met on three occasions to provide advice, react to the conceptual framework developed up to that point, provide many important suggestions as to how the work should proceed, and react to the written materials which emerged from the project. This group included David Armstrong, Director of the Center for Interdisciplinary Studies; David Hill, Chairman of the Geography Department; George Maler, Associate Dean of the College of Engineering; and Wesley Yordan, Chairman of the Economics Department, all from the University of Colorado; Roscoe Davidson, Superintendent of the Englewood schools; Norris Harms, Educational Consultant; Charles McNerney, of the Department of Mathematics at the University of Northern Colorado; Eric Miller, junior high school science teacher with the Boulder Valley Public Schools; and Harold Pratt, Science Supervisor of the Jefferson County schools. All these people made important contributions, but additional note should be taken of the contributions of two people who did work beyond the specific group meetings. Norris Harms helped to conceptualize the results of the first stage of questionnaires in the Delphi study, and Wesley Yordan helped identify the type of economic analysis needed for the project.

Since the overall design of the project, the analysis decisions, and the writing of the entire report were the work of the first author, none of the persons acknowledged above can be held responsible for what is presented in this report. Their contributions were many and significant, but the first author must take responsibility for the final product.

Ronald D. Anderson

January 1984

EXECUTIVE SUMMARY

The education of American students in science and mathematics today is inadequate; numerous reports have documented that students are not sufficiently well prepared for living in an increasingly scientific and technological world. As with other complex public issues, a careful cost-effectiveness analysis potentially can identify promising solutions for the "crisis" in science and mathematics education.

The process employed involved an assessment of both the cost and effectiveness of dozens of actions or interventions proposed as solutions. Early steps included identifying the objectives of the actions, the alternative interventions, and measures of their effectiveness. Once estimates of cost and effectiveness had been made, models relating costs and effectiveness were developed and recommendations prepared. In the process competing value judgments were recognized and taken into account.

The Process

The first step in the process moved beyond the varying definitions of the "problem" by formulating a set of objectives encompassing the many interventions under consideration. Three objectives were selected as representative of the intent of the many proposed interventions receiving public attention today.

a. Quantity. Increase the amount of time in which students are engaged in learning science.
b. Quality. Increase the quality of instruction in science classes.
c. Appropriateness. Increase the "match" between actual classroom objectives and those objectives most appropriate in today's world.

The interventions proposed in various quarters for improving science education are numerous. For purposes of this analysis, they were grouped into eleven categories and each of the eleven categories was attached either to the one of the three above objectives it most closely fit or it was associated with a fourth grouping labeled as facilitating interventions; i.e., categories of interventions that, though not necessarily promoting directly the attainment of any of these objectives, potentially are of benefit in changing some aspect of schooling that in turn will foster attainment of one or more of these objectives. The eleven categories of interventions, grouped by objectives, are presented below.

A. Interventions primarily related to Objective #1: Quantity
   1. Increasing student requirements
B. Interventions primarily related to Objective #2: Quality
   1. Preservice preparation of teachers
   2. Enhancing teaching as a career
   3. Improving instructional practice
   4. Inservice education
   5. Improving materials, facilities and equipment
   6. Assistance from business and industry

C. Interventions primarily related to Objective #3: Appropriateness
   1. Improving school curricula
D. Facilitating interventions
   1. Improving local leadership
   2. Testing programs
   3. Public education

Listed within these eleven categories were sixty-eight specific interventions. For example, the increasing student requirements category included such specific interventions as increasing graduation requirements, lengthening the school year, increasing homework, and increasing the proportion of class time devoted to instruction. An analysis was done to estimate the cost of implementing each one and to determine a rating of its effectiveness based on research data and such other information as was available. As single interventions, few gave much promise of being both low in cost and high in effectiveness.

Conclusions

The major conclusion of this analysis is that it is pointless to seek solutions to the problems of science education in the form of single interventions. The situation is systemic; solutions must be sought in the form of combinations of interventions with full regard for the interactions among these interventions. For example, inservice education for teachers has little potential as a single intervention, yet it probably is a critical component of a combination of interventions intended to produce most changes in the classroom. In combination with such other actions as curriculum development and effective leadership from principals, there may be substantial potential for educational improvement. The removal of a critical element from this endeavor (i.e., inservice education), however, may negate the effect of the total set of actions. An action which by itself may have minimal effect may, by its absence in another setting, result in a minimal positive effect from other interventions.

Dealing with these combinations of interventions and their interactions requires a conceptual framework that relates the interventions. This structure was acquired from the research on effective schools, implementing educational change and the leadership of principals. The implications of this research are that (1) combinations of interventions are necessary, (2) the completeness of this combination may be critical, i.e., the absence of one particular intervention may seriously impair the effect of the package of several interventions, and (3) a multi-level approach is needed, i.e., some actions should be taken at the building level, some at the district level, some at the state level, and some at the federal level. Further implications of this research are that all change endeavors should be coordinated, and focused upon the local level where possible. A multi-level approach requires state and federal actions, but all action at these levels should be taken with full recognition of the importance of local "ownership" and commitment.

A State Plan

The core of the recommendations is a state plan of action intended to foster local initiative and draw federal assistance into a concerted state endeavor. It will require strong leadership at this level. Among the coordinated set of state-level interventions constituting this program are to:

- --provide funding and professional assistance to local leadership. and science education improvement programs
- --fund improved teacher education programs
- --provide training for local district personnel on curriculum development and implementation
- --fund multi-district consortia for curriculum development
- --provide information for local school board members on needed improvements in science education
- --provide conferences for local district testing personnel on appropriate science tests
- --establish a science test item bank with items on the applications of science knowledge
- --provide awareness conferences and other information for local accountability committees concerning science education improvement
- --establish leadership for the above interventions which will enable them to proceed in a coordinated manner with appropriate modifications as indicated by evaluation and communication with local education personnel.

Local Action

The basic intent of these coordinated interventions is to stimulate local initiative in a systematic manner which promotes the quantity, quality, and appropriateness objectives. Local leaders will be encouraged to pursue a systemic approach including attention to several means of achieving each objective.

Quantity

- --increase graduation requirements in science
- --increase homework (coordinated with classwork)
- --help teachers in more fully utilizing instructional time

Quality

- --foster teacher recognition and professional development, and an improved professional environment
- --improve teacher recruitment and selection
- --provide increased suoervision and assistance focused upon the improvement of instruction
- --introduce improved instructional practices
- --conduct inservice education which supports the other interventions

Appropriateness

--support local science curriculum development

Facilitation

--initiate improved program evaluation and programs of science education improvement
--initiate careful selection and preparation of principals and supervisors.

Federal Action

Federal action should be sought which fosters the local and state endeavors described above. Specifically included are the following actions.

--provide inservice and summer teacher institutes that are tied to and supportive of local district improvement endeavors
--support curriculum development projects with particular emphasis on the application of science knowledge
--fund consortia of school districts for developing curricula for their schools
--fund research to increase the knowledge base needed for appropriate curricula, analysis of science education problems, and identification of actions needed for improvement
--provide an awareness conference for test publishers on the need for items emphasizing the applications of science knowledge
--provide funding to sustain state programs as described above.

A Systemic Approach

The proposed state plan is a coordinated response to a systemic problem; the basic intent is to foster local initiative utilizing all resources available, including federal funds. Each intervention in the total plan contributes to an overall approach; an intervention or two selected from each level of this listing and implemented in the absence of the others does not hold much promise of a significant impact.

Mathematics

The analysis and recommendations for mathematics are quite similar to those presented above for science with the exception of those pertaining to the appropriateness objective. The question of what mathematics is most appropriate for students to learn is a different question from the analogous question for science.

PART I. A COST-EFFECTIVENESS ANALYSIS OF INTERVENTIONS FOR IMPROVING SCIENCE EDUCATION

Chapter 1. Cost-Effectiveness Analysis: An Aid to Policy Decisions

The specific technique employed in this endeavor is cost-effectiveness analysis. Before simply describing its application to the problem at hand, it may be well to examine briefly the process itself; what is it, and what are its advantages and limitations? With this background, it then will be possible in the remainder of this chapter to examine more fully the relationship between decision-making in the political realm and policy analysis using a variety of techniques sometimes referred to as "rational techniques" by students of policy analysis (Carley, p. 3).

Defined broadly, cost-effectiveness analysis is "any analytic study designed to assist a decision-maker in identifying a preferred choice among possible alternatives."[1] More narrowly defined, it involves "a comparison of alternative courses of action in terms of their costs and their effectiveness in attaining some specific objective."[2]

Cost-effectiveness analysis sometimes is considered a variation of cost-benefit analysis, an approach which analyzes alternative actions in terms of cost and benefits, both measured in dollar terms. Cost-effectiveness analysis measures costs in dollar terms but evaluates outcomes in other units. "Cost-effectiveness analysis tries to show how a given level of benefit can be achieved at a minimum cost, or to show how the maximum benefit can be achieved at some given level of cost. The keynote of both of these problems is that it is not necessary to attach any explicit money value to benefits."[3] The methodology cannot be prescribed as a precise set of standard procedures but must be viewed as a general approach with a sequence of general steps. They include:

"1. Definition of objectives
2. Identification of alternatives
3. Selection of effectiveness measures
4. Development of cost estimates
5. Selection of a decision criterion
6. Creation of models relating cost and effectiveness."[4]

Other analysts such as Quade describe the process in similar terms although the number of steps and their sequence may vary slightly.[5]

Objectives

The definition of objectives is a particularly crucial starting point since the remaining steps are built upon the particular objective specified. Stated improperly, the objectives can produce an analysis that misses the intended target. In the case of the project at hand, this step is particularly important since the objectives were not specified in precise terms and provided to the analyst in advance as givens. Instead, reference often is made in rather general terms to the problems faced in science and mathematics education today and an expressed desire to find cost-effective steps for bringing about improvement and thus alleviating the problems.

Alternative Actions

Identification of alternative actions was a relatively easy step for this project in that large numbers of them have been advocated and widely reported in the popular and professional literature. While objectives have not been stated precisely, numerous alternative interventions have been widely advocated. A key step in this project was developing a list of such interventions (a representative list, though not exhaustive) and organizing them in some manner that would make them amenable to cost-effectiveness analysis.

Effectiveness Measures

Widely publicized problem statements, as well as the specific objectives implied by proposed interventions, point to a variety of effectiveness measures. While for many projects a single effectiveness measure may be appropriate, in this endeavor a total of three distinctly different ones were employed. They relate to (1) time engaged in learning, (2) student learning as measured by tests, and (3) changes in curriculum goals. Although not mutually exclusive, these three effectiveness measures by-and-large deal with different objectives and different intended changes in science and mathematics education. The rationale for choosing these three is developed later in the report.

Cost Estimates

A variety of costs must be taken into account in estimating the price of a particular intervention. Some costs are direct and others are opportunity costs; some costs are borne by the taxpayer, some by teachers and still others by students. In general, reasonably good estimates of these costs can be obtained. Specific means by which they are calculated and summarized to provide a final cost estimate for a particular intervention are described in Chapter 3.

A Decision Criterion

"Three types of valid criterion from which the analyst must choose are: 1) maximize effectiveness at a given cost; 2) minimize cost while attaining a given effectiveness; or 3) some combination of these two which recognizes a tradeoff of cost for effectiveness to maximize a selected utility function of the two factors."[6] The latter approach was chosen in this study; the complexity of the situation dictated this choice.

Creation of Models

Having completed the above steps, there still remains the problem of identifying analytical relationships among costs, effectiveness, and the context in which the interventions are to be initiated. This task was particularly difficult in this project because the analysis indicated early that the long list of single interventions under consideration could not be treated as single interventions. The situation is highly systemic and some combination of interventions must be examined within the context of school districts having a wide range of cultural, socio-economic and political variations.

Having described the essence of the cost-effectiveness analysis methodology as it pertains to this project, it is well to turn attention briefly to some of the advantages and limitations of the approach. The obvious advantage of the technique is its potential for identifying those interventions which can be done at lesser cost and produce effects worthy of the expenditure. The nature of the political process is such that it tends to focus on the direct expenditure of tax dollars with insufficient attention to opportunity costs and costs to such groups as teachers and students. The more objective process of cost-effectiveness analysis focuses attention upon all costs. The advantages of this analysis with respect to effectiveness probably are even greater; the usual tendency is to make many assumptions about the effectiveness of proposed interventions. Each intervention seems to have its advocates and the nature of the political process is such that particular interventions often win out because of who is promoting them, or other political factors, rather than some objective appraisal of their effects. In this project, extensive efforts were made to use objective data, drawn from careful empirical research whenever possible, to draw conclusions about the effectiveness of a particular intervention.

A second major advantage of a rational technique is its clarification of the value judgments involved. "This explicit specification of causal relationships can also help to expose value judgments which all parties to a decision bring to that decision. . ." (Carley, p. 67). "Value judgment or ideology within rational techniques is inevitable and value neutrality impossible. . . . It is essential that value judgments be expected and made as explicit as possible in the analysis" (Carley, p. 71). Value judgments are numerous and prominent in this particular analysis. This prominence is illustrated by the fact that one of the three objectives deals with changing the goals of instruction in the schools. The pervasiveness of value judgments was highlighted even more by the results of a series of questionnaires given to selected Colorado leaders as a subsidiary part of this overall analysis. The results showed sharply that there are two rather distinct camps in our society with respect to the goals of science education.

As valuable as this process of analysis is, it has its limitations. First, any analysis is necessarily incomplete. There are obvious limitations of time and money. In addition, one must recognize that even with adequate resources there is no way to treat all of the factors that impinge upon the situation. Too many factors are intangible and the result is that the analyst must employ his intuition and judgment, even though the decision-maker who refers to the analysis at a later time rightfully may choose to apply a ... judgments and intuition.

Second, the process of cost estimation is not as precise as it may appear on the surface. "Unfortunately, the preparation of cost estimates remains for the larger part an art. Methods are, to a great extent, adapted to the problem at hand. Many subjective elements are included in the cost estimate. The availability and reliability of data are always variable. In sum, the individual skill, experience, and natural resourcefulness of the cost analyst emerge as the critical factors."[10]

Third, measures of effectiveness necessarily are incomplete. Quade notes that in general, "One cannot be as confident about the accuracy of estimates of effectiveness as about cost estimates."[11] That generalization about cost-effectiveness analysis applies in particular to this specific endeavor. Measures of educational effectiveness in which one can place confidence are notoriously difficult to find. A variety of such measures have been used in this study and they are presented here with considerable confidence, but one must not attribute to them more precision than they deserve.

A final limitation is the fact that there is no satisfactory way to forecast future events in our society or educational system. Future events may alter the conditions which were assumed for this analysis. While not as big a problem as some of the other limitations noted above, it must be recognized.[12]

Having defined the process of cost-effectiveness analysis and noted some of its advantages and limitations, attention can be turned again to the relationship between the decision-maker and the analyst. The task of conducting the analysis described above has been assigned to someone referred to here as the analyst. When completed, the results will be given to decision-makers who will use it to some degree or another in the political process. While conducted largely independently of the political process, the results of the analysis are intended to be used in the political arena. "The role of policy analysis is to enlighten the policy process from its <u>particular</u> perspective, which is not expected to be completely comprehensive. Such enlightenment may take the form of espousing one explicit welfare function over another, based on its particular merits, or it may simply, but importantly, involve exposing new facts and details which fuel political debate."[13] A particular benefit of this analysis is consistency in the means of determining the cost and effectiveness of various alternative interventions. It also has a cost to the decision-maker, that of making explicit the decision-maker's objectives and exposing them to the scrutiny of other people.[14] Such scrutiny may be costly in the political process but it also has the advantage of making it possible to hold others more accountable for their actions when decisions are made on rather explicit objectives.

Chapter 2. Analysis of Science Education Interventions: Conceptual Framework

With the previous description of the cost-effectiveness process as a basis, attention can be turned to the conceptual framework for this particular analysis of the cost-effectiveness of interventions for improving science education. The interventions under consideration include most of the major actions proposed by various commissions, task forces, committees and political leaders in the last two years.

A cost-effectiveness analysis of alternative means of reaching some objective requires that one know what that objective is. Such a statement seems obvious, yet identification of objectives is more often overlooked than one may care to admit. In reflecting on today's political rhetoric about education, as well as commission and committee reports, it is easy to recall talk about costs. Each presidential candidate is proposing so many hundreds of millions of new dollars for certain activities to improve education. Yet careful delineation of what changes can be expected as a result is quite rare. It may seem at times that the "throw money at the problem" approach is being used with the expectation that something good will result. The objectives generally are not well defined.

It also should be noted that it is possible to do the cost portion of a cost-effectiveness analysis without well defined objectives, but it would not be possible to do the effectiveness analysis without well defined objectives. We not only must know what the problem is that is being addressed, but we must know what results are being sought to bring about some solution to the problem. In practice, the processes of defining the problem and identifying the objectives probably benefit somewhat from being done simultaneously. Although one may start by defining a problem, specifically delineating the desired results or objectives helps to more precisely define what the problem is. So in formulating a set of objectives for interventions intended to improve science education, one must consider whether these desired results are solutions to our real problems.

After careful consideration, three objectives were selected as representative of the intent of the many interventions which have been proposed to improve science education. They are as follows.

a. Quantity: Increase the amount of time in which students are engaged in learning science.
b. Quality: Increase the quality of instruction in science classes.
c. Appropriateness: Increase the "match" between actual classroom objectives and those objectives most appropriate in today's world.

Before examining these objectives one by one, note that they are all expressed in terms of instruction rather than learning. This was a deliberate choice reached after much consideration. One might argue that the objectives should be expressed in terms of student learning since that ultimately is our goal--to increase student learning. But for purposes of this cost-effectiveness analysis it is better to use objectives expressed in terms of instruction because the connection between the intervention and these instructional outcomes is more direct and there is a better basis for conducting an analysis that will show relative costs and effects. The ultimate concern about learning is important, however, and cannot be ignored. So, one should consider carefully instructional goals of the schools and be sure that they are truly the ones desired, based on what is known about the relationships between instruction and learning. They can be examined one by one.

A current concern is that our students need to know more science, and research shows a very direct relationship between the amount of time devoted to learning and the amount of learning that takes place. The frequently cited "time-on-task" research, as well as findings embedded in numerous other research studies, points to this conclusion. This research base, one that goes beyond conventional wisdom, is important because it firmly establishes that additional time spent learning will be effective and that a "point of diminishing returns" is not likely to be reached in our typical school settings. So, it is with considerable confidence that we set one of the instructional objectives as increased time engaged in learning with the expectation that it will result in greater learning.

The second objective of increasing the quality of instruction is more difficult to define and more difficult to demonstrate as having an impact on learning, but it appears, nonetheless, to be important. Calls for increased quality of education generally refer to increased teacher competence in terms of knowledge of science, skill in teaching, or dedication to the job. Only occasionally does increased quality refer to better facilities, equipment and materials. Since this matter of quality includes so many dimensions, it is not feasible to make a simple demonstrable link between quality of instruction and learning. There is evidence for a link between learning and some of these indicators of quality, but that issue is the heart of the cost-effectiveness analysis itself. Many of the interventions which have been proposed for improving science education are focused upon what has been labeled here as quality. In this analysis, each intervention is examined individually as to its potential impact on student learning based on the research information available.

The third objective of appropriateness deals with the question of what should be taught; the science taught should be that portion most appropriate for students in today's world. On the surface it is a simple matter, but in reality it is not, because it is based upon value judgments. In addition, the value judgments held by different individuals generally are based upon a variety of assumptions and conventional wisdom which often do not hold up under careful analysis using the results of research. In addition to the cost-effectiveness analysis *per se*, considerable attention must be devoted to what might be termed value clarification, i.e., determining the basis of various value judgments about what knowledge is of most worth and sorting out the erroneous assumptions and inaccurate pieces of conventional wisdom so one can arrive at valid judgments.

It may be helpful to examine briefly some examples of competing value positions. Some people would argue that the science taught should be whatever is most representative of the particular science discipline under consideration; the expected student outcome is an understanding of the structure of the discipline, its major principles and concepts, and some of the details needed to understand the "big picture." Scientific knowledge is valuable for its own sake. Others would argue that the science taught should be that which is most important for meeting the personal needs of students. Biology, for example, should emphasize the knowledge which is of most help in understanding the human body and making decisions about personal health, nutrition and the prevention of disease. With this focus, instruction on decision making and using biological knowledge to make these decisions would be taught directly as part of the curriculum. Yet another focus would be to emphasize that knowledge which is of greatest value in addressing societal issues such as, energy, world food supplies, the environment, nuclear power, national security, and health, among others. Students would learn the science knowledge needed to address these issues and proceed further to learn how this knowledge would be used in addressing these issues. Again, decision making and problem solving would be relevant as students learn the process of applying knowledge to identifying the optimum solution among many competing alternatives with respect to the given societal issue.

It also must be recognized that what is appropriate knowledge for one type of student may not be the most appropriate knowledge for students with different backgrounds or goals. An adequate analysis must give attention to this possibility and allow for differences among students. Furthermore, these orientations, i.e., attention to academic preparation, personal needs, societal issues, and so on, are not mutually exclusive; one focus does not have to be eliminated entirely to allow for another. A thorough analysis must take account of the various alternative emphases and combinations of them.

Now that the three objectives have been described, attention can be focused on the process of cost-effectiveness analysis, per se. Conceptually it is a simple process. Each possible intervention or action to improve science education can be analyzed to determine what it will cost to implement and what effect it can be expected to have. In practice it is more complex because of a lack of good information in many cases, and the potential interaction among the interventions. A framework for this analysis, which gives the simple conceptual view, is shown in Figure 1.

In the lefthand column is a place to list the many interventions to be considered. Across the top are the three objectives discussed previously. Under each of the three objectives is a place to indicate the expected cost and expected effect of each intervention for that particular objective. Thus, for each intervention there is a place for cost and effect information with respect to all three objectives. In the case of most interventions, however, there will be a significant impact on only one of the objectives; most often an intervention has little potential for meeting more than one objective.

The key part of the cost-effectiveness analysis is obtaining the needed cost and effectiveness information. The best information is empirical data acquired in typical school settings. Cost information, for example, can be obtained from representative school systems, federal or state agencies or other organizations which have introduced an intervention. In cases where an intervention has not been used previously, estimates can be made based upon descriptions of what the intervention is.

Valid effectiveness information generally is more difficult to obtain. The best source is well designed experimental studies which provide data on the effect of the given intervention as compared to the effect of conventional practice without the intervention. The educational research literature is extensive; it is a larger and better data base than often realized. Efforts must be exerted, however, to seek out the data relevant to the effect of a particular intervention.

In spite of all these efforts, however, gaps will remain for which no empirical data are available. In these cases the analyst is left with no option but estimates. While such estimates probably are an inadequate basis for all decisions about particular interventions, they may be adequate for eliminating some potential interventions as so lacking in promise as to be

Interventions	Objectives					
	Quantity		Quality		Appropriateness	
	Cost	Effect	Cost	Effect	Cost	Effect
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						
13.						
14.						
15.						
16.						
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Figure 1. Objectives-Intervention Matrix for Cost-Effectiveness Analysis of Alternative Actions for Improving Colorado Science Education.

unworthy of a careful test, while other interventions may be identified as having sufficient promise to be worthy of such tests.

Having described the cost-effectiveness process in broad outline, attention can be turned to the set of interventions being considered in this analysis. The number of possible interventions is large, a fact that is evident to anyone familiar with even a few of the many recent commission reports, proposed pieces of legislation, and political statements. In this project an attempt has been made to be inclusive, considering as many interventions as possible, yet limiting the endeavor enough to make it manageable. This approach has been pursued by grouping the possible interventions into broad groups, eleven in number, and including within each group at least the major possible interventions. In some cases, the interventions included for analysis include essentially all the major interventions under serious consideration by any leader or leadership group. In other cases, the number of possible interventions is large enough that all cannot be included. The list of eleven intervention categories is shown below along with examples of specific interventions in each category. (The number and letter combination used to label each of the eleven categories is derived from an organizational pattern imposed in the next chapter, but is included here to make cross-referencing easier.)

A.1. Increased Student Requirements. Improving the amount of student learning in science and mathematics through such means as:

a. increasing the graduation requirements in science and mathematics for all students,
b. increasing college admission requirements in science and mathematics for all incoming freshman students,
c. increasing the length of the school day or the school year,
d. increasing the amount of homework,
e. increasing the proportion of total class time that is devoted to instruction,
f. increasing the proportion of scheduled school days actually devoted to classes, and
g. increasing the academic requirements (grades) for student participation in athletics.

B.1. Preservice Preparation of Teachers. Improving the preparation of new science and mathematics teachers through such means as:

a. new standards for preparation programs,
b. greater science and mathematics requirements for elementary school teachers,
c. specialized preparation programs for science and mathematics teachers in grades 4-6,
d. more courses emphasizing the applications of science and mathematics,
e. more "hands-on" work as part of teacher education programs,
f. placing student teachers only with outstanding teachers,
g. stronger enforcement of the requirements that districts hire only fully credentialed teachers (not hired on emergency certificates), and
h. loans or scholarships for persons preparing to be science or mathematics teachers.

B.2. Enhancing Teaching as a Career. Enhancing teaching as a career through such means as:

a. increasing the salaries of teachers in all fields,
b. increasing the salaries of teachers in science and mathematics to be competitive with alternative employment,
c. establishing performance pay for teachers,
d. providing an improved professional environment within school districts,
e. developing other incentives for attracting and retaining teachers,
f. initiating campaigns to enhance local teacher recognition and respect,
g. improving teacher recruitment and placement services,
h. involving teachers with researchers in collaborative educational research,
i. more emphasis on professional growth, including better supervision and evaluation of teachers, and
j. reducing work loads, i.e., fewer students per class and fewer classes per day.

B.3. Improved Instructional Practices. Improving instruction through such means as:

a. improved student-teacher ratios,
b. mastery learning, and
c. computer-assisted instruction.

B.4. Inservice Education of Teachers. Improving the inservice education of teachers through such means as:

a. summer institutes for science and mathematics teachers at all levels (with federal or state funds),
b. academic year, full-time institutes for science and mathematics teachers (with federal or state funds),
c. "institute classes" in late afternoon and evenings during the school year (with federal or state funds),
d. inservice education courses on the applications of science and mathematics,
e. inservice education classes on higher level aspects of science and mathematics,
f. inservice education courses on teaching methods,
g. inservice education programs coordinated with local endeavors (with federal or state funds),
h. teacher centers where teachers can work together on program development as well as inservice education,
i. extended year contracts for teachers for program development work,
j. improved teacher evaluation as a basis for professional growth and inservice education, and
k. sabbatical leaves for professional growth.

B.5. Improving Materials, Facilities and Equipment. Improving the quality of science teaching by providing more and better materials, facilities and equipment through such means as:

a. state or federal funding of local district needs, and
b. local district increases in budgets for materials, facilities and equipment.

B.6. Industrial Assistance. Improving science and mathematics education through various forms of assistance from business and industry such as:
a. providing seed money for educational projects,
b. providing cash awards for individually determined programs of personal and professional development which are sponsored by and named for particular industries,
c. donating equipment,
d. loaning lecturers or workshop leaders to schools,
e. rotating employees into classroom teaching for a time,
f. assisting in evaluating curricula,
g. providing industrial internships for teachers for 2 months in summer, and
h. hiring teachers as part-time (e.g., summer) employees.

C.1. Improving School Curriculum. Improving the school curriculum through means such as:
a. developing more courses showing the applications of science and mathematics for personal uses and solving problems,
b. developing more rigorous science and mathematics courses for college-bound seniors,
c. reducing the number of "frill" courses,
d. federal funding of new curriculum development projects,
e. revising the "old" NSF science courses by expanding or replacing portions with local materials,
f. developing model curriculum patterns for districts to consider (by federal or state agencies or professional associations),
g. providing training for local districts on how to develop curricula and implement them,
h. developing regional consortia of schools and universities to develop curricula,
i. states or groups of states setting new standards for the textbooks to be adopted, and
j. improving program evaluation.

D.1. Improving Local Leadership. Providing greater leadership for science and mathematics education through such means as:
a. increasing the number of science and mathematics supervisors within local school districts,
b. weighting program development more heavily in the job descriptions of district science and mathematics supervisors,
c. weighting science and mathematics program development more heavily in the job descriptions of general curriculum personnel, and
d. state or federal funding of local district plans for providing greater leadership.

D.2. Testing Programs. Improving instruction through new tests which are more consistent with science instructional goals through such means as:
a. awareness conferences and training in test preparation for district-level personnel who develop tests for their districts
b. developing banks of appropriate test items and making them available for local school district personnel to draw upon, and

c. informing established citizen-accountability groups of the need for this improved testing and encouraging them to use their influence to assure that appropriate modifications in tests are made.

D.3. Public Education. Generating greater public understanding and support of K-12 science and mathematics education through such means as:

a. various media advertising to promote the idea of students taking more courses in science and mathematics,

b. television programs for students such as 3-2-1 Contact, and

c. preparing publications for elected officials, such as school board members, which describe the current problems with science and mathematics education and means for solving these problems.

Chapter 3. Projected Costs and Effectiveness of Single Interventions

While they are grouped within the indicated eleven categories, each specific intervention in each category must be examined individually to determine its projected cost and effectiveness. As noted earlier, however, limiting the analysis to separate individual interventions would be inappropriate because of the systemic nature of the situation under consideration. Thus, in the next chapter of this report, attention will be turned to the value of various combinations of interventions. A specific analysis for each single intervention, however, must be done first.

For purposes of describing the projected costs and effectiveness of the interventions, the eleven categories are grouped within four clusters. These four clusters are the three objectives described earlier (quantity, quality, and appropriateness) and a fourth cluster designated as facilitating interventions. Each of the first three of these clusters contains one or more categories of interventions which are expected primarily, though not exclusively, to directly promote attainment of that particular objective. The fourth cluster, facilitating interventions, contains categories of interventions which, though not necessarily promoting directly the attainment of any of these three objectives, potentially are of benefit in changing some aspect of schooling that in turn will foster attainment of one or more of these objectives. The four clusters and the categories of interventions contained within each one are presented in Table 1.

Estimating the cost of a particular intervention requires that attention be given to possible costs to a variety of agencies and individuals such as federal and state government and local school district expenditures, teacher and pupil costs, and costs incurred by industry in the case of donations from that sector. The type of costs included are both direct costs and opportunity costs. Table 2 contains a definition of each of the cost categories including state and local district expenditures (S & L), federal expenditures (F), expense and opportunity costs incurred by teachers (T), educational opportunity costs for pupils (EOC), expense and opportunity costs for pupils and their families (P), and costs incurred by industry (I).

A full description of the costs for each intervention and the basis on which each was calculated are contained in Appendix A. A summary of these costs is given here in Table 3 where S & L and F have been summed together under the column headed "Tax Monies" and the EOC and P categories have been summed together under the category labeled "Pupil Cost."

All costs presented in these tables are presented as the cost per pupil per year. Some costs were substantial sums which were prorated over a number of years. For example, the cost of remodeling a school classroom to convert it to a science laboratory was prorated over a ten-year span. In another instance, inservice education was assumed to have a "life" of five years and was prorated over that period of time. The only costs not presented in this manner were the costs of public education (one of the eleven intervention categories). In most cases, the cost per pupil per year is in essence the cost of providing the particular intervention for the sake of one class in which that student will be participating over the period of one school year. For example, an intervention which causes the student to take an additional

Table 1

Interventions Grouped by Primary Objective

A. Interventions Primarily Related to Objective #1: Quantity

1. Increasing Student Requirements

B. Interventions Primarily Related to Objective #2: Quality

1. Preservice Preparation of Teachers
2. Enhancing Teaching as a Career
3. Improving Instructional Practice
4. Inservice Education
5. Improving Materials, Facilities and Equipment
6. Assistance from Business and Industry

C. Interventions Primarily Related to Objective #3: Appropriateness

1. Improving School Curricula

D. Facilitating Interventions

1. Improving Local Leadership
2. Testing Programs
3. Public Education

Table 2

Definitions of Cost Categories

Code	Cost Category	Description
S & L	State and local district expenditures	Includes all direct expenditures by school districts, the source of which generally is state or local funds. It also includes any direct expenditures by the state for programs initiated at that level.
F	Federal expenditures	Includes all direct expenditures by the federal government for the given intervention. To whatever extent federal funds indirectly support an intervention through regular school district budgets, it is included in S & L above. It also includes the cost of tax reductions received by industry for their donated assistance as described below.
T	Expense and opportunity costs incurred by teachers	Includes all direct expenses incurred by teachers or prospective teachers and opportunity costs resulting from their participation in the intervention.
EOC	Educational opportunity costs for pupils	Reduction in non-science education due to reallocations of time and resources to science education. It is valued at its cost.
P	Expense and opportunity costs for pupils and their families	It includes all expense and opportunity costs incurred by either pupils or their families with the exception of educational opportunity costs contained in EOC above.
I	Costs incurred by industry	Costs incurred by industry as a result of their donations to science education reduced by the amount of the tax benefits they receive for their donation.
TOT	Total	Total of all of the above categories.

Table 3

Costs of Single Interventions
(Dollars per Science Student per Class per Year)

Intervention	Tax $ (S & L and F)	Teacher Cost (T)	Pupil Cost (P and EOC)	Industry Cost (I)	Total
A. Quantity					
1. Increased Student Requirements					
a. Increase graduation requirements (1 course)	$30.02		$600.00		$630.02
b. Increase college admission requirements (1 course)	30.02		600.00		630.02
c. Increase length of school year (4 weeks)	333.40		536.00		869.40
c. Increase length of school day (1 hour)	500.00		401.99		901.99
d. Increase homework	1.59		100.50		102.09
e. Increase percentage of class time used for instruction	1.59				1.59
f. Increase scheduled days used for instruction			60.00		60.00
g. Increase academic requirements for participating in athletics			301.50		301.50
B. Quality					
1. Preservice Preparation of Teachers					
a. New standards for teacher preparation programs	2.88	$8.96			11.84
b. Greater science requirements for elementary teachers	1.15	3.58			4.73
c. Specialized science teachers in grades 4-6	2.88	8.96			11.84
d. More courses emphasizing applications of science	1.39	3.58			4.97
e. More "hands-on" work in teacher education programs	10.99				10.99

Table 3 (continued)

Intervention	Tax $ (S & L and F)	Teacher Cost (T)	Pupil Cost (P and EOC)	Industry Cost (I)	Total
1. Preservice Preparation of Teachers (continued)					
f. Student teachers only with outstanding cooperative teachers	0.18	0.30			0.48
g. Employ only fully certified teachers					N/A
h. Interest-free loans for prospective teachers	11.39				11.39
2. Enhancing Teaching as a Career					
a. Increasing salaries of all teachers ($3000)	$26.88				$26.88
b. Increasing salaries of science teachers ($3000)	2.15				2.15
c. Performance pay	3.58				3.58
d. Improved professional environment					N/A
e. Local teacher recognition campaigns	0.08				0.08
f. Improved teacher recruitment and placement	0.09				0.09
g. Involve teachers in collaborative educational research	5.35				5.35
h. Better supervision and evaluation	3.58				3.58
i. Reduced workload	240.00				240.00
3. Improving Instructional Practice					
a. Improved teacher-student ratio	240.00				240.00
b. Mastery learning	1.82	$0.27			2.09
c. Computer-assisted instruction					N/A

Table 3 (continued)

Intervention	Tax $ (S & L and F)	Teacher Cost (T)	Pupil Cost (P and EOC)	Industry Cost (I)	Total
4. Inservice Education of Teachers					
a. Summer institutes for teachers	2.57	0.09			2.66
b. Academic year, full-time institutes	44.15	7.09			51.24
c. Late afternoon or evening institute classes	2.18	0.27			2.45
d. inservice on application of science	1.82	0.27			2.09
e. inservice on more advanced aspects of science	1.82	0.27			2.09
f. Inservice on teaching methods	$1.82	$0.27			$2.09
g. Inservice coordinated with local development	1.82	0.27			2.09
h. Teacher centers	2.11	0.27			2.38
i. Extended year contracts for program development	6.42				6.42
j. Improved teacher evaluation	3.58				3.58
k. Sabbatical leaves	23.12				23.12
5. Improved Materials, Equipment, and Facilities					
a. Improved materials, equipment, and facilities	5.30				5.30
6. Industrial Assistance					
a. Seed money for educational projects	0.72			$1.07	1.79
b. Providing cash awards	0.72			1.07	1.79
c. Equipment donations	0.72			1.07	1.79
d. Loaning lecturers and workshop leaders to schools	0.49			0.73	1.22
e. Rotating employees into classroom teaching	30.46			45.70	76.16

Table 3 (continued)

Intervention	Tax $ (S & L and F)	Teacher Cost (T)	Pupil Cost (P and EOC)	Industry Cost (I)	Total
6. Industrial Assistance (continued)					
f. Evaluating and developing curricula	0.12			0.18	0.30
g. Summer employment for teachers	4.94			7.40	12.34
C. Appropriateness					
1. Improving School Curricula					
a. Developing more courses with science applications (local)	0.59				0.59
a: Developing more courses with science applications (federal)	0.05				0.05
b. More rigorous courses for college bound (local)	0.59				0.59
b: More rigorous courses for college bound (federal)	$0.05				$0.05
c. Reducing number of "frill" courses					N/A
d. Federal funding of new curriculum development projects	0.05				0.05
e. Revising "old NSF" courses locally	0.30				0.30
f. Developing model curriculum patterns for districts	0.05				0.05
g. Training for local personnel on curriculum development and implementation	0.13				0.13
h. Regional consortia for curriculum development	0.30				0.30
i. New standards for textbook adoption	0.05				0.05
j. Improving program evaluation	0.03				0.03

Table 3 (continued)

Intervention	Tax $ (S & L and F)	Teacher Cost (T)	Pupil Cost (P and EOC)	Industry Cost (I)	Total
D. Facilitation					
1. Improving Local Leadership					
a. Increasing the number of science supervisors	3.00				3.00
b. Revised job descriptions for local science supervisors	0.75				0.75
c. Revised job descriptions for general curriculum personnel	0.75				0.75
d. State or federal funding of local leadership development program	3.50				3.50
e. Training for school board members	0.05				0.05
2. Testing Programs					
a. Awareness conference for local testing personnel	$0.01				$0.01
b. Test item banks for local personnel	0.02				0.02
c. Awareness conferences for test publishers	0.01				0.01
d. Informing local accountability committee members	0.05				0.05
3. Public Education					
a. Media advertising to promote science education	<0.01				<0.01
b. Science television programs for public	0.35				0.35
c. Adult education courses on science and technology					N/A

course in science is an intervention that affects one class of the student's school day over the period of one school year.

While the cost calculations assume an "average" sized school district, it is recognized that the costs and feasibility of many interventions will vary with the size of district. In most cases these variations do not significantly alter the conclusions drawn from the analysis. In those cases where it does, this effect upon the conclusions is discussed in connection with the specific intervention, e.g., curriculum development or testing programs.

Many readers may be inclined to attach more importance to the costs contained in a particular column than some others. For example, the taxpayer or political leader may be inclined to give most weight to tax monies expended and attach lesser importance to a matter such as "Pupil Cost" in the form of opportunity costs or lost wages to the student as the result of spending more time in school. While various individuals may have different value judgments in this regard, one should not lose sight of the fact that all the costs described in this analysis are costs to society and that other individuals may well have different values as to their relative importance.

The reader may wish to refer to Table 3 while reading this chapter since costs are only described in general terms in the chapter narrative. For purposes of discussing the various interventions, however, these general descriptions of costs as low, medium, or high may be most appropriate. In some cases, of course, more precision can be attached to the information for a given intervention, but when one considers the substantial variations in the conditions under which it could be implemented, caution should be exercised about implying too much precision.

The criteria for effectiveness vary among the objectives; they will be discussed within the context of each objective. On the pages which follow, the cost and effectiveness of each intervention are addressed one by one within the four clusters of objectives. At the end of the chapter, several matrices will be presented which portray the relative costs and effectiveness of each of the single interventions within each of the clusters of objectives.

A. Interventions Primarily Related to Objective #1: Quantity

The criterion for effectiveness of the various interventions proposed for this objective is time engaged in learning. It could be argued that the basic criterion should be scores on tests of student learning, but to facilitate this analysis, the criterion ideally should have as close a linkage as possible with the intervention. The criterion of time engaged in learning has been shown by considerable research to be highly related to student learning. So the criterion of increased time engaged in learning will be used in lieu of increased student learning.

All of the specific interventions under consideration with respect to this intervention are in the category of increasing student requirements. Each one is examined individually as to its cost and effectiveness. Note that this category involves significant costs for both the taxpayer and students; both costs are considered.

a. Increasing the graduation requirements in science for all students. This intervention consists of increasing the required number of science courses in junior and senior high schools. For example, a senior high that currently requires one science course for graduation may increase the required number to two courses.

Costs: The costs for this intervention are medium for the taxpayer and high for the pupils. Theoretically at least, the students will simply take less of some other courses so they can take more science. Thus, the total number of teachers, classrooms, textbooks, etc., will not change. But there are some real costs, including what may be called transition costs. A substantial cost would be remodeling classroom space to provide science laboratories and stocking them with the necessary supplies and equipment.

There are other less visible costs of this intervention. One is the loss of student learning in areas other than science. To whatever extent other courses are not taken because of the new science requirement, the student loses knowledge from the other area. In essence it is a simple trade-off but it still must be recognized as a cost, since there are other interventions which potentially will increase time for science that do not have this cost.

Yet another potential cost (not included in the cost calculations) relates to the current shortage of qualified science teachers. To whatever extent additional science teachers must be hired from among candidates with substandard qualifications, the overall quality of U.S. science teaching is lowered. Similarly, if non-science teachers in a particular district are reassigned to teach science because their major teaching area has lost enrollment due to the increased science requirements, the overall quality of science teaching is lowered. In some cases it may be feasible to retrain non-science teachers so they are qualified to teach science, in which case the cost involved may be that of retraining. Both costs, the costs of retraining teachers and the cost of inadequate science teaching due to a lowered quality of teaching, are real costs.

Effectiveness: The effectiveness of this intervention in terms of the given objective is potentially high. To whatever extent the new science requirement is higher than the amount previously taken it will result in students being engaged in science learning for a greater period of time.

Further analysis, however, leads to some important reservations about the potential effectiveness of this intervention. Most of the college-bound students in a typical school already are taking more than the minimum required amount of science. Thus, the increased requirements will have little effect on this portion, roughly half, of the school population. The group it will affect is largely the non-college-bound students, sometimes referred to as the general or non-academic student. Since increasing the scientific literacy of all students is generally regarded as an important goal, this intervention still seems to be an attractive one, but some other considerations appear. Heed also must be paid to another of the three objectives, namely the appropriateness objective. Is the current science curriculum of high schools designed for the college-bound students or is it appropriate for all students? It probably is not appropriate for all students, so the appropriateness issue also must be dealt with before a final answer can be given on the effectiveness of this particular intervention. This situation illustrates the systemic nature of the issue at hand and leads to a final conclusion: this intervention will have high effectiveness in increasing the amount of time engaged in science learning if the appropriateness objective also is attained.

b. Increasing college admission requirements in science for all incoming freshmen. This intervention consists of increasing the number of high school science courses a student must have taken before a college or university admits them for study. The number currently required for admission to colleges ranges upward from zero, a not uncommon minimum, to a high of two (in all but a few unusual situations).

Cost: The cost analysis for this intervention is similar to that of the previous intervention, i.e., medium for the taxpayer and high for pupils.

Effectiveness: Since this intervention must be implemented by individual colleges, its impact on the number of students taking more science in a given high school is likely to be relatively small, or at least very gradual, unless (1) the number of colleges making the change is large and (2) the increase in requirements is not only beyond current requirements but beyond what the incoming students currently take. The effectiveness of this intervention is difficult to determine without data on both current requirements among colleges and on the number of credits in high school science among incoming college freshmen. Several institutions recently have increased their admission requirements from two to three years of science.[15]

Implementation of this intervention probably will vary widely among colleges. The many colleges (about 40 percent) with an "open-door" approach, i.e., admit any high school graduate, probably will not introduce a science requirement since it would require a fundamental change in a basic institutional policy. Most of the colleges having certain requirements for admission also compete with each other for students during this non-growth era. Thus, they often are reluctant to increase admissions requirements of this nature unless their "competition" is doing so also. Only a minority of institutions of higher education probably are in a position to take unilateral action on a change of this nature.

Colleges probably will take action on this intervention if it appears it will improve their own programs. In that regard, college personnel are advised to review the research on the effect of high school preparation in science on college science performance, information which will be examined briefly in a latter section of this report (see page 53).

c. Increasing the length of the school day or the school year. This intervention consists of increasing the amount of time students are in school each day or lengthening the school year by some number of days or weeks. This action could be taken at either the state or local level, although state action is probably the key since state financial support for schools commonly is tied to student attendance.

Cost: The cost of this intervention is high for both the taxpayer and pupils. For the taxpayer, the cost is approximately a prorated portion of the current non-capital expenditure portion of the cost of schooling. The current non-capital annual per pupil expenditure in Colorado is approximately \$3,000.[16] Assuming a 180-day school year, the additional per pupil cost of extending the school year would be approximately \$83 per week. Similarly, if the school day were extended by 17 percent, i.e., by adding one more class to each student's schedule or lengthening each class by 17 percent, the anticipated cost would be an approximate 17 percent increase in the non-capital expenditures portion of the budget or an annual increase of approximately \$500 per student. For the pupil, the opportunity costs are high if either the school day or the school year is lengthened.

Effectiveness: Assuming that students would participate in an extended school day or school year at the same rate as the current program, this intervention would be effective in increasing the amount of time students would be engaged in learning science. This intervention is not differential with respect to science. The time engaged in learning would increase proportionately for all subject areas. The impact is quite predictable and measurable. Since non-capital expenditures constitute the largest portion of school budgets , the cost and effect are close to directly proportional.

d. Increasing the amount of homework assigned to students. This intervention consists of a change in the instructional practices of teachers. While basically a simple increase in the amount of homework assigned, a change in the character of the homework probably should be considered also.

Costs: The cost of this intervention is quite low for the taxpayer and medium for students. It has virtually no impact on most parts of the budget, even for supplies. Consideration should be given, however, to the cost of inservice education for teachers in how to develop valuable homework, activities which are an integral part of the classroom instruction and have the highest probability of being done by the students. To whatever extent such changes in instructional practice are related to changing the curriculum, there may be some costs relative to curriculum improvement. All things considered, however, it is a low cost change.

Effectiveness: Although one cannot simply generalize the results to the high school setting, there is research conducted at the college level which offers some insights as to the potential of this intervention. The research literature on college teaching shows that what a college professor does to influence how students use their time outside of class has more impact on student learning than any other aspect of their instructional work.[17] Other research at the secondary school level shows directly that increased homework can be used to increase student learning.[18] To whatever extent the high school teacher can influence students to do more work outside of class, there is every reason to expect it will not only increase the amount of time engaged in learning but increase learning as well. When compared to the amount of time spent in class, an additional 20 minutes per day engaged in learning outside of class is a substantial amount of time. This arbitrary figure of 20 minutes per day is picked for illustrative purposes only, but the basic point is to emphasize that an increase in homework from zero to 20 minutes per day or from 20 minutes per day to 40 minutes per day, is a substantial increase and has the potential, if done properly, of significantly increasing the amount of time students are engaged in learning.

The success of this intervention is probably dependent upon some of the other potential interventions. For example, improving local leadership may be necessary to provide the stimulus and assistance to put this intervention into practice. Similarly, inservice education focused directly upon this intervention may be necessary and a change in the school curriculum may be of help. These interrelationships give further impetus to the idea that the total process of making change in the schools is systemic.

e. Increasing the proportion of total class time devoted to instruction. This intervention consists of fostering teacher behavior change such that more time is devoted to instructional activities and less to socialization, administrative details, and maintaining order. These other functions are important, but the basic thrust of this intervention is that student time will be devoted as much as possible to learning. Research indicates that the average amount of class time in which students are actively engaged in learning varies greatly from teacher to teacher, from as low as 50 percent to a high approaching 90 percent.[19]

Costs: The cost of this intervention is low for both taxpayer and student. Costs for the school are essentially those of motivating teachers and helping them acquire the new behaviors needed to make this change. These costs basically are for well designed, targeted, inservice education and additional supervision and support to assist in implementing the desired changes.

Effectiveness: The effectiveness of this intervention, if implemented, is high, as indicated by two pieces of data. The first is the wide variation in the current percentage of time "on task" as indicated above. Secondly, data on the effectiveness of training programs designed to help teachers in this realm indicates change can be made.[20]

f. Increasing the proportion of scheduled school days actually devoted to classes. This intervention consists of reducing the number of class periods or entire school days devoted to "non-instructional" activities such as pep rallies, assemblies, and other special activities.

Costs: The cost of this intervention is low for every party involved; it is basically the loss of student involvement in other activities.

Effectiveness. The effectiveness of this intervention in increasing the amount of student time engaged in classroom work is largely a function of the extent to which it is implemented. To whatever extent a particular school does devote a large amount of time to such "non-instructional activities," there is the potential for making an effective change. The amount of time devoted to assemblies and similar school activities in a representative suburban school district was found to be 4.1 percent.[21] This amount of time, less than 1½ hours per week, is not large enough that a significant amount of additional instructional time could be found here.

g. Increasing the academic requirements (grades) for student participation in athletics. This intervention consists of increasing the minimum grades required of a student before he or she may participate in the athletic program.

Costs: The cost of this intervention is low for the taxpayer and medium for the students affected. It is essentially the loss of athletic experience on the part of some students who would no longer qualify to participate in athletics.

Effectiveness: The impact of this intervention on the amount of time students spend in learning (whether in or outside of class) is hard to determine. The strong desire many students have for participating in athletics, however, may indicate it could be a significant motivator. The current requirement basically is that a student be doing passing work in four subjects. In Colorado, a student cannot have failed more than one course the previous semester.[22] The number of students whom this intervention would affect, however, probably is quite small; it would affect only a small minority of athletes unless the requirement were raised substantially.

B. Interventions Primarily Related to Objective #2: Quality

As indicated earlier, quality of instruction is more difficult to define than quantity of instruction and it is more difficult to demonstrate that whatever we define as quality has an impact on learning. Calls for increased quality of education most often refer to increased teacher competence in terms of knowledge of science, skill in teaching or dedication to the job; occasionally increased quality refers to better facilities, equipment and materials. Since quality includes so many dimensions, it is not possible to make a simple demonstrable link between it and learning. Various indicators of quality must be addressed one by one in connection with particular interventions. Each will be examined individually as to its potential impact on student learning based on available research information. The single interventions in this section are grouped within six categories including preservice preparation of teachers, enhancing teaching as a career, improving instructional practice, inservice education, improving materials, facilities, and equipment, and assistance from business and industry. The costs of the interventions in these six categories are to the taxpayer or the teacher. Since these costs can shift from one to the other relatively easily depending upon district policy (e.g., payment or non-payment of teachers for participation in certain types of inservice education), no attempt is made below to distinguish between these two categories.

1. Preservice Preparation of Teachers

These interventions are intended to improve the preparation of science teachers prior to their initial employment. They pertain to all aspects of the college program including (a) general liberal arts background, (b) study in the major field, e.g., physics, chemistry, biology, or geology, and (c) preparation in professional education. Each of a series of interventions for improving some aspect of this preparation is analyzed here in terms of cost and effectiveness.

a. New standards for teacher preparation programs. The proposal is that units of state government certifying teachers establish new standards for preparation programs and enforce them in the credentialing process. Opinions vary as to what form these new standards should take and the intervention has to be analyzed in these somewhat undefined terms. Whatever the specifics, however, the intent is that the standards be more rigorous and demanding.

Costs: The cost of this intervention is low unless it requires the development and/or addition of new courses in a college program. If it is simply a matter of requiring teacher education students to take certain courses they did not take in the past, the impact on enrollments in courses in most institutions would be minimal and not result in significant programmatic changes. If, as assumed here, the new standards require the development of new courses or an increase in the length of the program, significant costs are involved.

Effectiveness: In order to evaluate the effectiveness of this intervention, one must have some knowledge of the relationship between such preservice preparation and teacher's subsequent performance in the classroom.

The relevant research findings are almost exclusively correlational so drawing cause and effect conclusions is problematic. In addition, the correlations between preservice preparation and teaching performance are very low. It is important to note, however, that these correlations are higher than the correlations between teaching performance and other teacher variables. The research shows that the better teachers cannot be identified on the basis of personality characteristics, for example. The research indicates, however, that differentiation can be made among teachers to some extent based on their science background, their preparation in professional education, and their general academic performance in college. The low correlations (on the order of .3 and at most .4, indicating a degree of association between 9 percent and 16 percent) do not give great hope that teacher preparation programs are a place where dramatic changes can be made.[23] Nonetheless, it is important to select and prepare teachers who are able students themselves, have a strong science background and who have good preparation in professional education. Both the medium cost and the positive correlations referred to above point to this as an intervention that should be pursued even though the resulting amount of change may not be as large as for some other interventions.

One must also recognize that other factors besides the nature of teacher preparation programs control the background of the teachers who are employed by local school districts. Teacher supply and demand probably control this variable more than the minimum standards established for teacher education programs. In addition, one must look at the nature of the specific activities included within a teacher education program. Specific changes in these activities are reflected in some of the other interventions within this category and will be addressed specifically in that context.

b. Greater science requirements for elementary school teachers. The intent of this intervention is to require that elementary school teachers receive more science training in their teacher preparation programs.[24] A typical minimum requirement now is two science courses.

Cost: The cost (low) is the loss on the part of the future teacher of some other knowledge that would have been gained in whatever other courses are being replaced or the cost of an increase in the total length of the teacher education program. Assuming that the student was enrolled in a state university or college, there is an additional cost to the state of providing that education. The additional cost to the student would be tuition, living expenses, and loss of income during the time which is devoted to further schooling.

Effectiveness: The positive, though low, correlations between science background and teaching performance hold out some promise for this intervention. One may also speculate that a teacher with more background in science would be more inclined to spend time teaching it. Since current data indicate that science typically is not taught as much in elementary school as official guidelines would indicate, this potential impact of the intervention may also be of consequence. Consideration of this possible impact leads once again to the systemic view of making changes in science education. If one of the priorities is to teach more science in elementary schools, this intervention also should be tied to such interventions as district efforts to increase the amount of time elementary school science is taught.

c. Specialized preparation programs for science teachers in grades 4-6. The intent is to prepare teachers who are science specialists for grades 4-6.

Suggesting this action implies concurrent attempts to departmentalize instruction in the upper elementary grades so teachers may specialize by teaching area. It is assumed that such an elementary teacher would have a minimum total science background of 30 semester-hours or more.

Cost: The cost (low) of this intervention is the loss of knowledge in other areas resulting from a shift away from other of courses in the prospective teacher's college program. If this preparation ultimately leads to employment in a specialized position teaching mainly science, the loss of background in other areas is not of major consequence. If such shifts in school practice do not occur, the cost may be significant due to a lack of preparation for teaching other subject areas in the elementary school curriculum.

Effectiveness: In view of the previously cited positive, though small, correlations between science background and teaching performance, this intervention is viewed as having a positive but small effect. Its full benefits require programmatic changes in schools as well.

d. More courses emphasizing the applications of science. This intervention consists of adding to the teacher preparation program courses focused on the applications of science, i.e., not just limited to science *per se* as in the typical science major. These applications would include many important aspects of technology, applications of science to the personal needs of people in such areas as health, energy conservation, and common technological devices, and such societal issues as nuclear power, environmental concerns, world food supplies, and national security. The typical college science major currently is lacking in attention to such topics.

Cost: Although a few courses of this nature have been added to the curriculum in many colleges and universities across the country, the number in a typical institution is relatively small. To whatever extent this intervention simply requires shifting to existing sections of courses of this nature, the cost (low) to students is the loss of information in some eliminated area. To whatever extent such courses must be added to the curriculum, the institution faces course development costs. They include faculty time and expenditures for new library materials and laboratory equipment needed for the courses. Implementation of this intervention may be facilitated by development of model courses in selected institutions. Federal grants to a limited number of institutions may be valuable in stimulating the spread of such courses.

Effectiveness: This intervention is related more to the objective of appropriateness than it is to quality. Given the extensive efforts probably required to bring about changes in appropriateness, as will be described in a later section of this report, this intervention by itself is probably of little consequence. On the other hand, this intervention potentially could be a significant contributor to a multifaceted endeavor to bring about change with respect to the third objective--appropriateness.

e. More "hands-on" work as part of teacher education programs. The basic point of this intervention is to make teacher education courses less theoretical and more "practical," e.g., directed more toward development of materials, planning for instruction, and working with K-12 students in actual school situations.

Cost: The cost of this intervention may be resources for developing modifications to an existing program without changing its length or it may require lengthening the program. It is a medium cost intervention.

Effectiveness: There are considerable indirect data indicating this intervention would have a positive impact, but the magnitude of the improvement is difficult to assess. Based on the limited information available, if fully implemented it probably has more potential for improving teacher education than any other single intervention in this category.

f. Placing student teachers only with outstanding cooperating teachers. This action implies greater care in selecting cooperating teachers with which student teachers are placed to insure that the cooperating teachers are truly outstanding and not just average. It assumes that placements currently are not made on this basis as much as they could be.

Cost: Two costs are involved in making such a change. One is the greater expenditure of time by university personnel in locating such teachers. The second cost is somewhat increased transportation costs for the student teacher. This increase in cost is low and is based on the assumption that these more selective standards will require going farther from the university to locate the cooperating teachers.

Effectiveness: There are few empirical data to establish the differential effects of placing student teachers with "outstanding" cooperating teachers as compared to "ordinary" teachers, although the conventional wisdom is that there is a major difference. Inferences from somewhat related research, e.g., studies of "modeling" for teaching particular teaching behaviors, support the contention that there is a difference. The magnitude of change likely to result is largely in the realm of speculation.

g. Stronger enforcement of the requirements that school districts hire only fully credentialed teachers, i.e., not hire teachers on "emergency certificates" or "letters of authorization." Data from a survey conducted by the National Science Teachers Association indicates that approximately 50 percent of the science teachers hired in the United States for the 1982-83 school year were not fully credentialed.[25] The intention of this intervention is to restrict school district's freedom to hire such teachers.

Cost: The cost of this action is low unless one carries it to its ultimate conclusion and faces the choice of having either a less than fully credentialed teacher or no teacher at all. Under these circumstances the cost of the intervention could well be having no teacher and eliminating instruction in the given science classes for that year. A possible long-range consequence is higher salaries paid to teachers in order to attract ones having the full credentials.

Effectiveness: This intervention is probably of little effect simply because when faced with the choice between no science instruction and science instruction which is of marginal quality, essentially all schools will opt for marginal quality rather than no instruction at all.

h. Loans or scholarships for persons preparing to be science teachers. This intervention is offering financial incentives to students who choose to enter a preservice science teacher preparation program; the intent is to attract students who would not otherwise enter them. Such financial incentives could be either interest-free loans or scholarships of varied amounts.

Cost: The cost of this intervention basically depends upon the amount of the financial incentive chosen. If interest-free loans were offered, the cost would be the interest expense; if scholarships are offered, the cost would be the amounts of the scholarships. On an interest-free loan basis, it is a medium cost intervention.

Effectiveness: The effectiveness of this intervention is difficult to determine. The best indication probably is gained from the effects of similar programs, such as the ROTC scholarships provided to students entering those programs. Data on the effectiveness of these programs are not substantial,[26] but ROTC personnel are of the opinion that they are attractive.

2. Enhancing Teaching as a Career

The attractiveness of a particular career is a function of many factors including salary and other compensation, recognition and prestige, and the very individual matter of personal satisfaction gained from the activity itself. The intent of these interventions is to make teaching more attractive through increased financial compensation, greater prestige and recognition, and what may be called "better working conditions" resulting in greater personal satisfaction. The expected result of this intervention is increased quality of teaching for several reasons: there would be fewer teachers employed with less than full credentials; there would be greater opportunity for employers to select better candidates from among a bigger pool of candidates; and the persons employed as teachers would have more motivation to do a quality job and more opportunity to do so because of their "working conditions." Each specific intervention is evaluated as to its cost and effectiveness in increasing the quality of teaching.

a. Increasing the salary of teachers within all fields. The intent is to raise the salaries of teachers in all fields with a resultant increase in the quality of education. This increase would be across-the-board for teachers in all fields at all levels of experience.

Cost: The cost of this intervention is high. Since a high percentage of school district expenditures are for teachers' salaries, an across-the-board increase of, say, $3,000 would result in a substantial increase in school district budgets.

Effectiveness: The effectiveness of this intervention is difficult to assess; to a large extent such assessment is speculation. Moreover, in doing this analysis it is important to distinguish between long-term and short-term effects. If the salaries of all teachers were raised substantially, it is reasonable to expect that a smaller percentage of persons currently employed as teachers would leave the profession to seek other employment. The extent to which the quality of teaching would rise as a result of this greater retention is difficult to determine. To whatever extent the better teachers are leaving at a higher rate than poorer teachers, halting this exodus would be influential. It would also be important to restrict this exodus if the more experienced teachers are the better teachers but the correlation between years of teaching experience and teaching performance is low. Based on available information, it would appear that as a short-term intervention this one is not likely to have a major impact.

This intervention is more important from a long-term standpoint if it improves the quality of people attracted to a teaching career. As indicated earlier, background in the subject field and preparation in professional education are related to teaching performance. Thus, to whatever extent the number of people employed on "emergency certificates" is reduced, the quality of teaching should be higher. Assuming that higher salaries do attract more people, the quality of teaching should rise. Assuming also that hiring officials are able to discriminate and select the better teachers, the quality of teaching should rise because these hiring officials will have a larger group of candidates from which they can select. If there are more persons credentialed as teachers than there are employment opportunities, there is an opportunity to increase the level of quality by this judicious hiring.

The likelihood that higher salaries will result in greater job satisfaction and thus better quality teaching is difficult to assess. Research indicates that among the three main motivators of teachers including salary, and personal satisfaction from the job itself, the latter is the major motivator.[27] This information still does not establish the extent to which salary is a motivator, however, and we have little information upon which a convincing argument can be made that this increased motivation would result in noticeably higher quality teaching. The major benefit of this intervention probably is the former one, attracting better initial hirees.

b. Increasing the salaries of teachers in science to be competitive with alternative employment. This intervention is essentially the same as the previous one except it is limited to teaching fields, such as science, where there is a shortage of teachers.

Cost: The cost of this intervention is the same as the previous one with the exception that it is applied only to those areas in which there is a shortage. As a result, it is a high cost action. If applied only to those fields and not to those where supply and demand are in balance or where the number of teachers available is larger than the number of jobs, this intervention would pertain to the physical sciences and earth sciences, but not to biology. Additional costs may be associated with any conflict arising from differential pay by subject field, a matter of some controversy among teachers.

Effectiveness: The analysis of the effectiveness of this intervention is similar to that of the previous one. It also should be noted that there is considerable variation across the country in the shortage of science teachers. The potential effectiveness of this action in a particular region, state, or individual school district should be judged in terms of the supply and demand situation pertaining there.

c. Establish performance pay for teachers. This intervention entails basing salary increases for teachers upon their teaching performance, in contrast to basing them simply upon the teacher's educational level and number of years of teaching experience as is the current situation in most school districts. Performance or merit could be determined by administrative personnel through a variety of means including student's performance on tests.

Cost: The cost of this intervention could be relatively low if one assumes that total salary increases will remain the same and only the means of distribution will change. Under this assumption increases would be made upon the basis of performance. The costs associated with the intervention are for developing a system of determining meritorious performance.

Effectiveness: The effectiveness of this intervention is dependent first of all on the ability of administrators to determine meritorious performance.

Given that the correlation between administrator ratings, student ratings and increases on student test scores is quite low, this consideration is of some consequence. Assuming it is possible to make these judgments, the intervention's long-term effectiveness is probably dependent upon the extent to which it causes good teachers to stay in the profession and poor teachers to leave because their salaries are not competitive.

d. Providing an improved professional environment within school districts. This intervention consists of "improved working conditions" such as fewer lunchroom and hall duties, better office arrangements, better secretarial support, and a reduced number of different "preparations," i.e., fewer different courses per day. These specific items are illustrative of a broader class of improvements.

Cost: The analysis of the costs of this intervention can be done in terms of specific examples listed above as illustrations of this type of intervention. Assuming that monitoring activities such as supervising lunchrooms and halls will be done by non-teaching personnel and that teachers will use the time released for additional preparation and student assistance and not to teach additional classes, the cost of this intervention is the cost of hiring the non-teaching personnel. If teaching is not changed and teachers are not freed up for additional preparation, however, there is a savings due to the difference in pay between teachers and non-teaching personnel.

The cost of additional office space is something that probably is effectively addressed only in the context of constructing new buildings and will not be addressed here. Additional clerical and secretarial help amounting to one such additional person for each 10 teachers is assumed in this analysis.

Effectiveness: The effectiveness of these actions is difficult to assess; basically we are left with speculation. In general, it can be said that these interventions are favored by teachers but there is little hard evidence to suggest a dramatic effect on the attractiveness of teaching as a career or upon the learning that occurs in a given teacher's classroom. At the same time, the cumulative effect of many such actions over time may be an important contribution to the overall status of teaching as a career. There are growing indications that actions which reduce the isolation of teachers from professional colleagues are of value.

e. Initiating campaigns to enhance local teacher recognition and respect. This intervention consists of such actions as programs to honor a "teacher of the year" in a particular school or district and public relations campaigns to develop a more positive public image of teaching as a career.

Cost: The low costs of teacher recognition programs generally involve administrative and secretarial time to publicize the program, obtain nominations, screen and select the nominee(s) and make the presentation. To whatever extent the recognition carries a monetary reward, this would be an additional cost. Most such campaigns are conducted with the personnel already employed in the district and the cost is modest. The cost of a public relations campaign, however, could be rather large depending upon the scope of the efforts.

Effectiveness: The effectiveness of these interventions is difficult to assess and largely a matter of speculation.

f. Improving teacher recruitment and placement services. This intervention consists of better procedures for identifying, selecting and employing new teachers on the part of school districts and the provision of placement services on the part of institutions of higher education or other agencies.

Cost: The costs of these endeavors can range from essentially zero to several hundred dollars per teacher depending upon the level of additional effort expended by recruiters or placement personnel. Essentially, however, it is low cost.

Effectiveness: In terms of overall impact on education in a large area such as a state or the nation, these efforts are unlikely to have much impact; other factors control the quality of teachers entering the profession. In terms of a given local school district, however, increased endeavors may improve its competitive position with respect to other school districts. In other words, a school district with a particularly good recruitment program may be able to obtain more than its "fair share" of the available quality teachers.

g. Involving teachers with researchers in collaborative educational research. This intervention would involve teachers in educational research projects in conjunction with professional researchers. The intent is to train teachers to some extent in the research process and gain their participation in research. The expected benefit is both better research and professional growth for the teachers.

Cost: To whatever extent this approach simply displaces current resources from one type of personnel to another type, the overall cost of the research remains the same. Training teachers to give them the needed research expertise would require funds and there are opportunity costs for the teacher's involvement. Essentially, however, it is a medium cost intervention.

Effectiveness: One of the benefits of this endeavor could be better quality research. In terms of benefits to teaching, a possible outcome for teachers is a better understanding of the educational process and related insights about the most effective ways to teach. Assessing the extent of this impact is rather difficult, though large gains seem unlikely. One other benefit of this activity may be increased income for teachers if it involves work beyond their regular teaching duties. Supplemental income for what is a direct professional activity with potential professional growth benefits is a positive outcome of this endeavor.

h. More emphasis on professional growth, including better supervision and evaluation of teachers. This intervention is directed toward improved professional practice through better supervision and evaluation by principals and other instructional leaders.

Costs: A significant cost of this intervention is inservice education for administrators to prepare them better for new endeavors. Even so, it is still a low cost intervention.

Effectiveness: The effectiveness of this endeavor was addressed to a considerable extent under c above. In addition, further benefits to students could accrue simply from improved professional practices learned and adopted, independent of any pay increases that may or may not be involved under a merit pay system. Studies of educational supervision indicate that changes can be made. This intervention relates somewhat to another category, improving school leadership, which will be addressed in a later section of this report.

i. Reduce work loads, that is, have fewer students per class and fewer classes per day for each teacher. While this intervention has the potential of enhancing teaching as a career, it is more likely to be utilized as a direct attempt to improve the quality of instruction. Thus, this intervention will be addressed in a future category devoted to improved instructional practices (3.a below).

3. Improving Instructional Practices

The interventions in this category are changes in the standard instructional practices employed in schools. A list of all such possible interventions would be very long, longer than feasible to address in this document. For this reason, only three are included as examples, each distinctly different from the others. Some instructional changes can be implemented by teachers on their own, even though assistance in making change would be helpful. Other interventions in this category would require action by both teachers and administrators, while still others are largely under the control of administrators or policy makers. All of them directly affect the nature of student experiences in the classroom.

a. Improved teacher-student ratio. This intervention, essentially the same as 2.i. above, would result in smaller classes for teachers. The intent would be improved instructional quality through reducing the number of students in each class.

Costs: The costs of this action are very high, affecting both school district operating budgets and capital expenditures. Smaller classes increase the need for teachers as well as classrooms. Thus, at least as an order of magnitude approximation, the educational cost per pupil increases in proportion to the teacher-student ratio. Reducing class sizes by 10 percent means the cost of education will increase by a percentage approximating 10 percent.

Effectiveness. A substantial body of research on class size establishes that it is related to student learning. The many studies on this topic were integrated through meta-analysis by Glass et al., and the results reported in their book entitled, School Class Size.[28] Although learning is correlated with class size, within the range of class size typically found in American schools one would not expect from this meta-analysis of research that reducing the average class size in a school district from, say, 30 to 27 (10 percent) would result in a substantial increase in learning. Its impact would be low.

b. Mastery learning. This intervention consists of implementing the instructional approach commonly referred to as mastery learning. It is included here as an example of a substantial number of instructional practices which could be adopted, though mastery learning has been shown to be more effective than most new instructional approaches in terms of student learning. Among its characteristics are well defined, specific instructional outcomes, instruction focused upon these objectives, and reteaching until such time as the student has acquired the desired outcomes. The rate at which a student proceeds is determined by the time it takes for him or her to "master" the objectives. Among the characteristics of this instructional approach are frequent testing and immediate feedback to the students. Similar instructional approaches sometimes are found under different names such as the Keller plan.

Cost: The costs for implementing this approach are relatively low. The most significant costs are teacher training in this instructional approach and support from knowledgable supervisors in implementing the process.

Effectiveness: Research shows this instructional approach to be very effective. In a meta-analysis of research on different instructional systems used in science education, this approach stood out among others under consideration. Students in experimental classes using this approach had an average performance on cognitive achievement tests equivalent to students at the 69th percentile in the control groups to which they were compared.[29] The effectiveness is significant, and the costs are low. There are indications from other research, however, that the benefits of this approach are due to a larger amount of time devoted to learning by students. Thus, the benefits of this technique may be obtainable by other approaches which result in greater student "engaged time."

c. Computer-assisted instruction. This intervention includes all the various approaches to learning with the assistance of a computer, such as computer-managed instruction, computer-assisted instruction and others. It must be differentiated, however, from instruction about the computer or how to use it. In the latter case, students are learning about the computer itself or how to use it for any of a wide variety of purposes other than education itself. In the former case, the one of interest here, the computer is simply a vehicle to assist in learning any of the subjects in the curriculum--in this case, science.

Cost: The costs of this form of instruction are high. The cost of the equipment is substantial and the cost of developing the software needed for instructional purposes is high. At the present time, there is a serious lack of quality software for teaching science.

Effectiveness: Studies of the effectiveness of computer-assisted instruction in science mostly have not yielded dramatic results.[30] Student learning is essentially equivalent to that in traditional classes. So for the short term, this intervention is not very encouraging. Costs are high and learning could be expected to stay about the same rather than improve. For the long term, computer-assisted instruction may have much more potential. Examples of computer-assisted instruction can be found in certain settings with certain materials that are quite effective. There currently is much activity in this realm but how long it will take for this intervention to become cost-effective is still a matter of speculation.

In summary, improved instructional practices are interventions with a wide range of potential in terms of their cost effectiveness. Although most of these possible interventions have not been specifically analyzed here, information has been provided illustrating that there are instructional approaches with the potential of being quite effective. It may be one of the more fruitful areas for seeking greater quality of teaching.

4. Inservice Education of Teachers

This category of interventions encompasses education intended to improve the professional competence of currently employed teachers. The rather lengthy list of interventions presented here includes several which focus on the form of the inservice education, several which focus on the topic of the inservice education, and others dealing either with less conventional forms of inservice instruction or inservice education related to other means of promoting professional growth. The differences between some of the forms of inservice education described below are small but they are often viewed as different types and thus will be treated separately here.

a. Summer institutes for science teachers. This intervention includes the "institutes" operated during the summer by the National Science Foundation (NSF) during recent decades. Focused mainly on science knowledge with only occasional attention to pedagogical issues, they were intended to upgrade the competence of science teachers.

Cost: Institutes of this nature were operated by institutions of higher education with financial support from the federal government. An additional cost to the teacher would be the difference between the stipend and what this teacher could earn in some form of summer employment. This lost income potentially would be offset to some extent by a salary increase due to receiving academic credit for participating in the institute and thus moving up on the salary schedule. A cost to the school district is the salary increase paid to this teacher as a result of the credit earned. All told, it is still a low cost intervention.

Effectiveness. The teacher institutes, both summer and other forms to be discussed below, were highly popular among teachers; they liked them and thought them to be valuable. Empirical studies of institutes in a variety of settings, however, did not provide much evidence of positive impacts on the quality of instruction.[31,32] In fact, there were even evidences of a negative impact, as surprising as that evidence may be. All told, we have essentially no evidence to support a claim that summer institutes, at least as practiced in the past, are effective in improving the quality of instruction in the schools.

b. Academic year, full-time institutes for science teachers. This intervention consists of inservice education activities similar to the summer institutes described above except for their length.

Cost: The academic year institutes were discontinued earlier than the summer institutes. Thus, direct cost information based on experience with them would have to be adjusted for inflation. Basically, however, the costs on a per person, per unit-time basis are the same as the summer institutes. The loss of salary for the teacher is large, of course, even though these institutes carried a $2,700 stipend. All told, it is a high cost intervention.

Effectiveness. Data on the effectiveness of academic year institutes is more positive than cited for summer institutes[33] above but to a large extent their impact is unknown.

c. "Institute classes" conducted in the late afternoon or evening during the school year. Sponsored by the same funding agency, but offered on a part-time basis in the late afternoon or evening while the teacher is fully employed, these activities have provided essentially the same type of instruction as other forms of NSF institutes.

Cost: The cost of the instruction itself is about the same as that provided in the summer programs. Because no teacher stipends were provided and attendance at these classes typically does not reduce the chance for other employment, the total costs are somewhat less. School districts also face the resulting additional costs from teacher's upward movement on the salary schedule. In summary, it is a low cost intervention.

Effectiveness: No information is available other than that cited above for the other types of "institutes."

d. Inservice education courses on the applications of science. This intervention is inservice education classes on the applications of science, i.e., science useful in addressing personal needs of students or societal issues. It is the first of three interventions listed here which address particular inservice education topics.

Cost: This endeavor is low in cost. The cost is estimated from the tuition costs of continuing education courses in which tuition covers the total cost of education. This cost sometimes is paid by the teacher and in other cases by the employing school district. An additional cost to the school district would result if academic credit moved the teacher up on the salary schedule.

Effectiveness: Effectiveness depends on the nature of the school curriculum and the extent to which greater emphasis is sought in the curriculum for the applications of science. If following the traditional curriculum, the content of such an inservice class would not apply very directly to a school system. In this case, a substantial impact upon teaching and learning is not likely. On the other hand, if changes are being sought with respect to objective #3, Appropriateness, to give greater emphasis to the applications of science, this particular intervention may be of considerable value. Even though the evidence suggests inservice education is unlikely to provide much curricular change itself, there is reason to expect it would be a critical element in a broad-based, multifaceted approach to attaining objective #3. This point will be addressed further in connection with interventions for objective #3, Appropriateness.

e. Inservice education classes focused on more advanced levels of science. The purpose of this endeavor is to give teachers more advanced understanding of their teaching field. The classes would provide information on various aspects of science, and move the teachers beyond their current knowledge. This instruction would be similar to that provided under the institutes described in 4.a., 4.b., and 4.c. above.

Cost: The cost would be the same as the previous intervention.

Effectiveness: Information presented earlier indicated a low but positive correlation between a teacher's knowledge of science and teaching effectiveness. Thus, there is a basis for thinking a course increasing the teacher's background in science would be effective in increasing student learning. This benefit would be in addition to any motivational value for the teacher. There is some additional information, however, indicating a possible point of diminishing returns from increased science knowledge as it pertains to a teacher's effectiveness. Some studies have shown, for example, that beyond 16 to 20 semester-hours in the particular science being taught, it is difficult to find a relationship between teaching effectiveness and a teacher's knowledge of the particular science. There are additional considerations, however, since science is a rapidly changing field and a teacher's previously current knowledge can become outdated in a matter of years. Thus some amount of inservice training or other means of learning is necessary for a teacher to maintain an accurate and up-to-date understanding of the field. There are other dimensions not always evident in tests of student knowledge. Several observers have noted, for example, that an important function of K-12 science courses is to eliminate some of the misconceptions students have about basic phenomena and avoid introducing new misconceptions. There is evidence suggesting that the absence of such misconceptions is important for students if they are to be successful in more advanced levels of science. For these two reasons, one is cautioned to not quickly dismiss the importance of science knowledge beyond what will be acquired in the initial 16 to 20 hours of college instruction in the field. Still, there is not strong empirical evidence to support the effectiveness of a large amount of advanced training in a given science field.

f. Inservice education classes on teaching methods. This intervention consists of inservice education classes addressing various aspects of teaching methodology and instructional practice. Specific pedagogical topics could be any of a large number including those mentioned earlier, such as how to employ mastery learning and how to increase the amount of time in which students are actively engaged in learning.

Cost: The costs of this intervention are the same as those described in d above.

Effectiveness: The effectiveness of this intervention must be evaluated both as a single intervention and as part of a larger multifaceted endeavor to produce instructional change. The evidence on the effectiveness of single isolated inservice education courses is not strong. On the other hand, inservice education may be an essential element in an overall process of implementing change. In fact, some objectives, such as changing selected teaching practices or changing some aspect of the curriculum, may be quite complex and involve several interventions, one or more of which, such as inservice education, may be critically important. Research on the process of implementing educational change provides support for the proposition that inservice education may be an endeavor which by itself is of minor value but in another context is one of the foundational building blocks of a successful process of change. It is yet another example of the systemic nature of the situation, a topic to be addressed again in a later section of this report.

g. Inservice education program coordinated with local development endeavors. This intervention is the first of five listed here which is of an unconventional form or in which inservice education is linked to some other programmatic endeavor in the schools. This particular one consists of inservice education classes offered in conjunction with program development in the school district. For example, a new curricular program may be introduced assisted by inservice education specifically designed for that purpose.

Cost: The cost of this form of inservice class would be essentially the same as the cost of inservice classes described in d above.

Effectiveness: The effectiveness of this type of inservice education course cannot be judged independently of its specific role in the overall program development endeavor. The systemic nature of attempts to bring about program improvement is such that its effectiveness can only be judged in that context.

h. Teacher centers where teachers can work together on program development as well as participate in inservice education classes. This intervention also is related to a broader set of activities, namely program development included in a teacher center. Such centers sometimes are largely under the control of teachers themselves and provide inservice education the teachers define as important for their work.

Cost: Again, the cost of the inservice education itself is essentially the same as indicated in d above, with some additional expenditures for program development or other teacher center activities.

Effectiveness: It is difficult to provide a measure of the effectiveness of the inservice education work itself in that its potential impact is largely a result of its relationship to other program development work being conducted simultaneously.

i. Extended year contracts for teachers for program development work. The basic feature of this intervention is to employ teachers for an additional number of weeks beyond the standard teaching year to develop new curriculum materials and conduct other program development work.

Cost: The cost of this action is simply a prorated extension of the existing salary of teachers. It is a medium cost intervention.

Effectiveness. This intervention has the potential of enhancing teaching as a career as described earlier; it also has some potential for increasing the quality of education directly. Its main potential, however, may lie in attaining objective #3, Appropriateness. If a more appropriate curriculum is being developed, this approach facilitates its actual development and produces active teacher cooperation in the process.

j. Improved teacher evaluation as a basis for professional growth and inservice education. This intervention consists of a teacher evaluation process to be used in identifying areas of teacher strength and needed improvement.

Cost: The cost of this intervention is described in connection with the merit pay intervention in section 2.c. above. It is low cost.

Effectiveness: Little information is available on the effectiveness of this intervention as the basis for inservice education.

k. Sabbatical leaves for the professional growth of teachers. In its most common form, this intervention consists of one semester of leave at full pay or one year at half pay for teachers to pursue their professional growth. The activities can take on many forms (generally with the approval of the school district administration) such as educational travel, curriculum development work, or attending a college or university to obtain an advanced degree.

Cost: The cost of this intervention is basically the cost of a teacher's salary (including fringe benefits) for one-half of the school year. This cost might be reduced by the savings from hiring as a replacement a younger and relatively inexperienced teacher who is at the bottom of the salary schedule. It is a high cost intervention.

Effectiveness: There are no little empirical data available on the effectiveness of this intervention in improving the quality of teaching.

5. Improving Science Materials, Equipment and Facilities

In contrast to other categories of interventions, this one includes only one basic intervention, namely improving materials, facilities and equipment available for science instruction in the schools. The word "materials" refers to consumable items used in science classrooms; most are paper products although there are a substantial number of consumable supplies used in laboratory work, such as chemicals. Textbooks also are included in this category. Equipment refers to durable materials with a relatively long life span used for demonstrations or student laboratory work. Examples are Bunsen burners, glassware, and electrical meters. Facilities refer to the furniture and rooms where science instruction is conducted.

Cost: Determining the expenditures which are part of this low cost intervention requires information on two general topics: (a) the costs of materials, equipment and facilities, and (b) the current availability of such items in the schools. Data obtained by one large school system with a good science program indicate that the average cost of expendable materials for an activity-oriented elementary school program is $2.50 per student per year. A typical cost for textbooks is $14.00 and they commonly are used in school systems for six to seven years before they are replaced. The current condition of materials, equipment and facilities in schools is somewhat difficult to determine. Conversations with science teachers and supervisors lead to the conclusion that many, although not all, school systems have most of the basic equipment they need to conduct their program. The same could be said of consumable supplies, although to a lesser degree. The majority of senior high schools seem to have most of the facilities they need for conducting a good science program. More would be helpful, but a general base of adequacy in this regard is fairly common. All of this discussion about costs rests on the assumption that the current program will continue as is, i.e., the number of students taking science courses will not expand and the curriculum will not be changed in any major way. If one or both of these assumptions do not hold true, i.e., if the number of science courses taken by students expands and the curriculum is modified to make it more appropriate for all students, additional costs are involved. It would be necessary in some cases to build or remodel facilities to provide adequate classroom and laboratory facilities for teaching science. Similarly, this expansion probably would result in a need for more laboratory equipment, both for demonstrations and student laboratory activities.

Effectiveness: Though the available information is sketchy, it does not provide great hope that the quality of school science programs will improve in a major way simply by the infusion of more materials, equipment and facilities. This conclusion is based on the status of these resources in the schools as described above and the lack of a research basis for saying that a greater amount of materials and equipment is important for improving science learning; there is a lack of data indicating substantially increased learning would result from providing more of these materials. Also, providing additional materials does not necessarily mean they will be used. The clearest data on this situation are available with respect to elementary schools. New science programs initiated in the 1960s and 1970s used a substantial amount of equipment as well as materials. Massive efforts were made to put these programs into effect in many school systems across the country. Data available today indicate that in many of these cases the equipment is sitting largely unused. Thus, there is some empirical basis for saying that equipment is not the critical element in the system; it is not the determining factor.

This analysis concerning effectiveness rests on the assumption that the curriculum will not change significantly. The situation obviously is systemic, however, and major attempts to improve the curriculum of the schools may result in a need for different materials and equipment than the schools currently use. Thus, rather than looking at this intervention singly, it may be best to consider other interventions, such as increased student requirements and a changed curriculum, as the more basic interventions with materials, equipment and facilities being only cost factors to account for in the cost-effectiveness analysis of these other interventions.

6. Industrial Assistance

This category of interventions includes several ways in which business and industry can assist in improving science education in the schools. They are of three general types: (1) donating money or equipment to assist the schools in various ways, (2) donating the time of personnel to assist the schools in some manner, and (3) offering employment to teachers during non-teaching times. Specific interventions in each of the three groups are discussed below. Many of these interventions are low cost but the cost to a particular industry may be quite high relative to their budgets if they were to initiate them for a substantial number of teachers.

a. Providing seed money for educational projects. The intent is for business or industry to provide a certain amount of "seed money" for initiating special educational projects not easily funded from the regular school budget. Such projects may be experimental in nature but with the potential of becoming permanent school activities if they prove successful in their experimental form.

Cost: The cost basically is determined by the amount of such assistance provided. It could be very small or quite large. In addition, if projects of this nature are chosen competitively, the administrative costs of selecting and monitoring projects will be involved.

Effectiveness: Determining the effectiveness of this intervention is very difficult since it depends upon the purpose to which the funds are put. The results of the cost-effectiveness analysis of the many interventions addressed in this report make it quite clear some interventions have considerable potential and others very little. The same in all likelihood is true of whatever activities would be supported through this intervention. The basic question of the purpose to which the money will be put is largely unanswered here.

b. Providing cash awards for individually determined programs of personal and professional development which are sponsored by and named for a particular industry. The intent of this intervention is to provide funds to support programs of personal and professional development for teachers. The nature of the activities may resemble some of those described in the section on Enhancing Teaching As a Career or Inservice Education; the specific activities will be determined on an individual teacher basis.

Cost: A program of this nature could be established at many levels. The most expensive form would require funding for teachers' salaries while absent from teaching duties as with sabbatical leaves described previously; others would be more modest. Along with salaries would be the cost of the professional growth activities themselves. The cost of such activities also is highly variable but could easily reach $5,000 over a period of an academic year if it involved considerable travel and highly specialized training.

Effectiveness: The effectiveness of this endeavor likewise is very difficult to determine because it is highly dependent on the nature of the specific activities, and by definition these activities can vary widely. In keeping with the systemic nature of the situation and the analysis of other interventions, it can be said that generally the most effective interventions are tied to some other positive action and are not done in isolation. The question of effectiveness must be addressed individual by individual; information on the potential of many specific actions by individuals can be acquired from the cost-effectiveness analysis of other interventions in this report.

c. Equipment donations to schools by industry. On occasion, business and industry have obsolete or unneeded equipment which they are willing to donate to the schools. To whatever extent such equipment is useful for instructional purposes, these donations can be an asset to the schools.

Cost: There are two basic costs to this endeavor. One is the cost to industry of donating this equipment, the salvage value of the equipment. A second cost is a loss to the public of tax revenues when the industry "writes off" the salvage value of the equipment as a tax deduction.

Effectiveness. Interviews with science supervisors in the state of Colorado do not provide strong evidence for the effectiveness of this intervention. The common opinion, based upon past experience, is that most of the equipment received in this manner is not particularly useful. Its original purpose was such that it does not have a lot of utility in the classroom and in addition, this donated equipment often is in poor condition. Such donations occasionally do result in schools receiving equipment of substantial value to them. On balance, however, this intervention does not have much potential for making a marked improvement in science teaching.

d. Business and industry loaning lecturers or workshop leaders to schools. This intervention is the first of three that provides the time of business personnel to the schools free of charge. Its intent is to provide the needed expertise in selected important areas.

Cost: The cost of this endeavor is basically the salary, benefits and support costs of maintaining the employee, prorated over the period of time this person is involved in the schools.

Effectiveness. Since lectures and workshops vary dramatically in quality and purpose, it is difficult to evaluate the effectiveness of this particular intervention. A reasonable maximum benefit one might anticipate is the maximum benefit occurring from inservice teacher education. In addition, activities for students have the potential for aiding their learning if the topics are well chosen, the content is coordinated with other parts of the curriculum, and the personnel are conscientious about the task.

e. Rotating business and industrial employees to classroom teaching for certain time periods. This endeavor is intended to alleviate the shortage of qualified science teachers by using personnel from industry as teachers. It is assumed that such employees with strong science backgrounds would have sufficient teaching skills that they could enter such employment on a temporary basis and provide quality instruction.

Cost: The major cost of this intervention is the differential in pay between a teacher's salary and the existing salary of the employee from industry. Under a common version of this intervention, business would cover the additional cost. A further cost to business would be the loss of talent in an area where they also may face a shortage that cannot be replaced at a comparable level. It is a high cost intervention.

Effectiveness: The effectiveness of this intervention is open to considerable question. Previously cited information about the teacher characteristics that correlate most highly with success as teachers indicates that both background in science and professional education are related to success as teachers. In general, the personnel identified for this type of intervention could be expected to have the background in science but it is unlikely that they would have the preparation in professional education. A different level of educational expertise is required for this intervention than in e above where business personnel would come in for short periods of time and do their instructional work within a context established by professional teachers.

f. Assisting in evaluating and developing curriculum. The intent is to have business and industrial employees participate in the on-going process of evaluating and developing curricula. They would not take over the process but broaden the range of expertise involved in the task. To whatever extent those personnel were trained in science and technology, they would bring important competences.

Cost: The cost essentially would be the salary, benefits and support services provided for the employee in his/her position in industry. It is a low cost intervention.

Effectiveness: The effectiveness of this intervention is related more to objective #3, Appropriateness, than it is to the objective of quality. Evaluating the curriculum to determine the extent to which it is focused on the most appropriate content and objectives is a crucial task and requires the insights of a wide diversity of people from many segments of society. Studies show that the perspective held by science teachers is basically that of university scientists under whose tutelage they were socialized as college students. The more technology and applications-oriented perspective of personnel from industry, as well as the viewpoints of people from a wide variety of other segments of society, are important in the democratic process of determining what should be taught. To whatever extent this intervention provides a portion of this diverse collection of opinions, it is of value for objective #3 concerning the appropriateness of the curriculum.

g. Providing industrial internships for the employment of teachers in the summer. The intent is for scientifically oriented industries to employ teachers for a period of time, say two months, in the summer. The purpose is to enhance teaching as a career by providing additional employment and removing the forced period of professional unemployment faced by most teachers each summer. In addition, this intervention will provide them with experience in a science-related industrial setting which will enable them to be better teachers of science and technology.

Cost: To whatever extent science teachers can step into positions which industry needs to fill on a temporary basis, and do so without substantial training, this intervention would have not cost. In reality, the training required for most industrial positions and the infeasibility of employing someone only for short periods of time arbitrarily determined by the school calendar, is such that there would be costs involved. In most cases, filling positions in this manner would not be the optimum approach and some additional costs would be incurred by business, although these costs could vary substantially from one setting to another. It is possible that some year-around positions which are vacated extensively during the summers because of vacations taken by the regular employees could be filled on a temporary basis by teachers. On average, it is a medium cost intervention.

Effectiveness: Although difficult to define in specific terms, it appears this intervention, if it could be implemented, would be of considerable benefit to science teachers and the teaching of science in the schools. It has the benefit of enhancing teaching as a career by eliminating the forced unemployment faced by most teachers for nearly one-fourth of the year. The employment that most teachers are able to find for this period of time usually does not require the scientific or educational skills of their profession. A further benefit of this intervention is the professional growth of the teachers involved; it potentially could provide them a setting in which they would learn an extensive amount about the applications of science, how technology influences our society, and some of the career options open to students.

C. Interventions to Attain
Objective #3: Appropriateness

The third objective, appropriateness, brings us directly to one category of intervention, namely, improving the school curriculum. The existing research results in this area are informative. ~~First, the research~~ establishes quite clearly that the science curriculum in the schools of this country is defined by the textbooks in use; teachers teach whatever is in the textbooks. Choices are often made from among what is contained in the book because it contains more than what can be covered in a particular course, but rarely is a significant amount of material added.[34] Secondly, the widely used textbooks in this country give little attention to the processes of science or the applications of science; science-related personal needs or societal issues receive little attention. Based on reviewing several studies, it appears that a good estimate of the average amount of science class time devoted to these applications of scientific knowledge is about 5 percent.[35,36] Science basically is viewed as important for preparing for the next level of schooling, not because it has some direct value in and of itself or for other applications of the knowledge.[37] These rather strong statements have a clear-cut research base; they are based on observations of the "real world." It is within the context of this reality that questions concerning the curriculum must be addressed. They involve a substantial number of value judgments although there is a substantial amount of empirical research information that must be considered in making these judgments. Without careful attention to the empirical research, it is easy to adopt value judgments which are based upon erroneous conventional wisdom.

Improving the School Curriculum

This group of interventions, the only one addressing the appropriateness objective, includes two general types of interventions. The first directly addresses particular changes in the curriculum. In essence, it is based upon value judgments as to what is appropriate. The second type of intervention focuses on particular mechanisms for bringing about desired change.

Note that all interventions described below for improving the school curriculum are low cost compared to the "quality" interventions described in the previous section.

a. Developing more courses showing the applications of science for personal needs and addressing societal issues. This intervention is intended to broaden the curriculum through courses giving more attention to the applications of science. Science knowledge *per se* is not to be eliminated but presented in a somewhat different context. To pick a rather arbitrary number as a point of departure for this analysis, let it be said that the intent is to switch from the current 5 percent of time in science classes devoted to applications of the knowledge to 25 percent of the time. This percentage is less than studies indicate teachers and the general public think would be ideal.

Cost: The costs of developing such courses vary dramatically. Inexpensive examples can be identified; a locally developed course recently received an award from the National Science Teachers Association yet was developed at a cost of approximately $25,000 (Jefferson County Schools' Topics in Applied Science).[38] In contrast to this example are courses developed with NSF funding a decade or two ago at a cost of $2 or $3 million. The $25,000 and the $2 or $3 million figures illustrate the vast range of the costs of developing a new curriculum package.

Effectiveness: Assessing the effectiveness of new courses moves one directly into the realm of value judgments; a choice must be made concerning the emphasis given to the applications dimension. The argument advanced here is that this applications dimension is highly important. Space does not allow a detailed argument in this regard, but it can be sketched in broad strokes. It begins with the nature of the world in which we live today; it is increasingly scientific and technological in nature. Many personal needs of people cannot be addressed adequately without science knowledge and our society faces many science-related issues which cannot be addressed adequately without substantial science knowledge. The argument goes a step further and is based upon what research says about the transfer of learning. Students do not automatically transfer the science knowledge learned in the abstract in conventional science classes to the personal applications or situations noted above. They learn to apply science knowledge to meeting personal needs and identifying optimum solutions to science-related societal problems by practicing this process of applying the knowledge.

If the argument expressed in the above paragraph is strongly held by many leaders and educated people in our society, and it is, why is this view not reflected more substantially in the curriculum of the schools? It is an important question and worthy of digressing slightly from the agenda at hand to gain some perspective. Surveys of teacher opinion, for example, show that teachers generally do agree with this argument; they say that the applications of science are important. In practice, as noted earlier, it is not a significant part of their teaching. When pressed to explain why they do not include it more in their teaching or why they do not choose textbooks that give it more attention, teachers will respond that they do not have enough time because there are so many parts of this body of science knowledge they must teach students so they will be ready for the next level of schooling, be that senior high, college or whatever. Research shows that this is the strong opinion of the vast majority of teachers.[39] On the other hand, research also shows that the science knowledge learned at one level of schooling generally is not critical for the next level of schooling. For example, numerous studies have shown that having or not having taken chemistry in high school is not a significant predictor of student success in college chemistry.[40] Another example: medical schools which in recent years have changed their entrance requirements to admit students without a strong science background, in addition to other students who do have the science background, are finding that both types of students do equally well in medical school.[41] Research shows quite clearly that the preparation notion is strongly held and it also shows there is little empirical basis for it. Teachers do not have to spend all of their time teaching the body of scientific knowledge in the abstract and in isolation from other considerations. Research offers no reason to resist shifting from the current 5 percent of class time devoted to the applications of science to some higher percentage, say 25 percent, or even more. There is no reason of substance for avoiding numerous topics which currently are seriously neglected in the curriculum because of the perceived need to prepare for the next level of schooling by learning the largest possible amount of abstract knowledge. Among the avoided topics which could be given attention are how scientific knowledge applies to personal needs, how scientific knowledge applies to a wide variety of societal issues, the processes by which scientific knowledge is acquired, something about the real life struggles of researchers, information about the limitations of scientific knowledge, problem solving and decision making in a scientific context, and how to think and learn on one's own outside the classroom.

b. Developing more rigorous science courses for college-bound students. The intent of this intervention is to develop new courses and instructional materials having a more advanced level of science knowledge than current advanced courses taught in U.S. senior high schools. They would be in addition to, or in replacement of, current college-oriented physics and chemistry courses common to almost all school districts and the second year advanced placement courses in biology, chemistry and physics found in some senior high schools.

Cost: As in the case of intervention a above, the costs of developing a course of this nature vary dramatically from relatively inexpensive to very expensive. To a large extent such course materials do exist, however, and the cost involved is not so much for developing the materials as it is installing them in the schools.

Effectiveness: The question of effectiveness of this intervention is again a value judgment about appropriateness. Two factors derived from empirical research are relevant to this issue. One is the previously cited research indicating that taking the current college preparatory science courses in high school is not a significant predictor of success in college science courses. Based on the results of this research, there seems to be little reason to think that more of the same would lead to more success in college.

A common interpretation of current research is that the top approximately 5 percent of students in the U.S. perform equally as well as the top 5 percent of students in Japan and other highly developed countries. The same cannot be said of other students in U.S. schools; the typical Japanese student, other than the top 5 percent, performs better than U.S. students. This information indicates that the major need is not to have even more rigorous work for the very top ability students but the need is to provide better science instruction for students of all levels of ability. A recent study conducted by the Office of Economic Research of the New York Stock Exchange identified the high quality of primary and secondary education in Japan as the single most important factor in its high economic productivity.[42]

This statement is not intended as an argument against an increase in the quality of instruction wherever possible in all types of science courses. The point of this argument is simply that developing more rigorous courses (i.e., changing the curriculum in this regard) is not an effective move for making the curriculum in U.S. schools more appropriate for its students.

c. Reducing the number of "frill" courses. This intervention is often espoused, but usually without specifying what frill courses are in mind. The courses so identified typically are not science courses. The usual targets are courses commonly considered less "academic." With respect to the science curriculum, this intervention in practice turns out to be essentially the same as one addressed earlier in this report, namely increasing the required number of courses in science. If the number of required science courses is increased, thee is less room in a student's program for other courses, whether they be "frill" courses or substantial courses in some area other than science. Thus, the cost-effectiveness analysis of this particular intervention is essentially the same as for the earlier recommendation on increasing the graduation requirements in science. The reader is referred back to that portion of this report (#A.a.) for further consideration of this issue.

d. Federal funding of new curriculum development projects. The intent is to use federal funding to establish new curriculum development projects patterned after the NSF-funded projects of the past quarter century. The purpose would be to develop new curriculum materials to meet current needs.

Cost: If established at the same level of funding as the earlier projects, these new endeavors are estimated to cost between \$500,000 and \$3,000,000 in 1983 dollars.[43]

Effectiveness: Research has established that the curriculum development projects of the past generation were successful in two senses. In terms of student learning on cognitive measures, and a variety of measures of other student attainment, such as laboratory skills, and understanding the methodology of science, empirical research shows that the new curricula were more successful than the "traditional" curricula they replaced. A statistical integration of the results of over 100 comparative studies shows that the average student in the new curricula performed at approximately the 62 percentile of the students in the control groups. These research results, based on studies including over 45,000 students across the country, were clear in their results. The new curricula also were successful in another sense;

the content was different from the traditional curricula they replaced. Furthermore, many of the textbooks produced by the major commercial publishers changed in content over time to be more like the new NSF-funded projects. The new curricula made a new content available and influenced the major textbooks appearing in subsequent years. In conclusion, there is strong evidence to indicate that new curriculum materials could be developed which would be successful with students and would have a new content emphasis in keeping with the important goals espoused for tomorrow's students.

e. Revising the "old" NSF science curricula by expanding them or replacing portions with locally developed materials. The intent is to develop new curricula but to do it on a smaller scale. Essentially, it would be taking the NSF-developed curriculum materials of the past generation and modifying them in accordance with current goals of science instruction. This approach assumes the extant NSF materials have many good portions but could be improved by major modification.

Cost: The cost of the projects for modifying extant curriculum materials should be considerably less than the full-scale curriculum development projects cited earlier. Costs would vary substantially depending upon the extent of the modifications, but an arbitrary figure useful for general planning purposes could be one-third to one-half the cost of a totally new endeavor.

Effectiveness: If the assumption is correct that major portions of the existing NSF curriculum project can stand as they are, and if one further assumes that the successful past experiences of developing materials can be repeated with a new emphasis, there is every reason to think new projects could be successful in developing materials which match current objectives, such as those emphasizing applications of science.

f. Providing training for local school districts on how to develop and implement curricula. This intervention will provide training for local school district leaders on developing new curriculum materials at the local level and introducing them to classes in these districts.

Cost: If one assumes that this particular intervention involves training only and not the funds for the development and implementation work following the training, the costs are not forbidding, though substantial. Assuming that this training is provided for one educational leader from each of the 181 school districts in Colorado, with the exception of the 20 largest districts where an average of 3 persons per district would be trained, the total number of trained people would be 221. If one further assumes the scope of this training is equivalent to six semester-hours of course work, the cost would be calculated on the same basis as for inservice education classes described previously.

Effectiveness: Based upon the results of research on curriculum development and implementation activities during the past couple of decades, it appears the effectiveness of this approach would vary substantially depending upon the aspect under consideration. The curriculum materials development aspect is considerably more complex than the implementation aspect. Based on information about the skills used in curriculum development[44] and knowledge of the qualifications of personnel in smaller school districts, it appears unrealistic to expect significant materials development in smaller school districts. On the other hand, in some of the larger districts with personnel having the required training and experience, a certain amount of materials development is a feasible expectation. Implementation of new curricula, on the other hand, is not only feasible but required in even the smallest districts if positive curricular change is to result. In this regard, it is well to note that research establishes the importance of local initiative and commitment if such change endeavors are to succeed. Change endeavors imposed from outside the district by either a "carrot" or "stick" approach are not likely to be successful.

g. Establishing regional consortia of schools and universities to develop curricula. The intent is to establish consortia of school districts and universities to develop new curriculum materials and put them into practice. Between the schools and the universities, the full range of expertise required for successful curriculum development should be available. It is further assumed that consortia of this nature, focused upon a particular region, can have the close links with member schools necessary for developing materials which fit the needs of the schools and are realistic for implementing under the specific local conditions.

Cost: Like the curriculum revision endeavors described in e above, this approach to curriculum development and implementation appears less costly than full-scale curriculum development projects. Some portion of school district personnel time already is devoted to curriculum improvement. To whatever extent this personnel time could be utilized more effectively under the auspices of the consortium, it would not be a new cost but simply greater productivity from current expenditures. Additional funds would still be necessary, however, from federal grants, state funds, or contributions of local school districts.

Effectiveness: Research on the federally funded curriculum development endeavors of the past quarter century indicates the development work itself generally was quite successful but the implementation of these programs in school systems frequently fell short. This research and other research on implementing change in schools points up the importance of local initiative and "ownership" as well as the need for a variety of specific tactics requiring intensive and extensive local school district participation. If the consortium under consideration here has the high quality personnel characteristic of past curriculum development endeavors, extensive participation and control on the part of local school districts, and sufficient resources for putting the programs into effect, there is considerable reason for optimism about its effectiveness.

h. States or groups of states setting new standards for adopting textbooks. The intent of this intervention is that states having statewide textbook adoption (or preferably a group of the major states) would establish new standards for textbook content. Rather than focusing simply on format, graphics, and politically sensitive issues (e.g., evolution and creation) common to recent textbook adoption committee proceedings, these standards would address the curriculum content issues noted in sections C.a. and C.b. above. By insisting that the books contain certain materials before they would be adopted, the major commercial textbook publishers could be "forced" to produce new materials with different objectives.

Cost: The cost of this intervention would be relatively small. Existing textbook adoption committees already have a budget for meeting and deliberating, as well as holding hearings to get opinions from the public and professional educators. With a relatively modest increase in budget, they could collaborate with such groups in a few other key states and arrive at a joint agreement on what they would announce ahead of time to publishers as requirements for new materials. The only additional major cost would be the development costs incurred by the publishers in meeting the new standards. Since publishers already are devoting significant money to developing new materials, a new orientation resulting from this process does not imply a significant increase in the cost of the textbooks when brought to the marketplace. Such additional costs would be a very low percentage of the cost of the books.

Effectiveness: Research has established that publishing companies do respond to the requirements established by state textbook adoption committees.[45] There is substantial evidence to support the proposition that publishers would comply if several key states, such as California and Texas, united together to insist upon particular features of science textbooks before considering them for adoption. Other curriculum development endeavors such as described in d and f, however, may be necessary before a state would have operational definitions of what they want.

i. Developing model curriculum patterns for districts to consider. The intent of this intervention is that federal or state agencies, possibly in cooperation with professional associations, develop model units or conceptual frameworks for curriculum materials which could be used as a basis for local school district development efforts.

Cost: The scope and character of this development work is similar to that described in e above. Thus, the cost would be similar to e. The intent is to develop model portions of a curriculum rather than an entire curriculum.

Effectiveness: The effectiveness of this intervention is based upon the assumption that local school districts actually would develop curriculum materials if models were available to them. Although some of this curriculum development work has occurred in few school systems across the country, the number is relatively small and thus the assumption seems somewhat tenuous.

j. Improving program evaluation. The intent is that local school districts develop more thorough evaluations of their curriculum programs. Some evaluation endeavors of this nature identify what actually is presented in the classroom, what is intended by the policy makers who adopted the curriculum, and what content is included in the district testing programs. The assumption is that this evaluation will identify discrepancies between what is desired, what is actually taught in the classroom, and what is tested. This information potentially will aid decision makers in making better decisions about curriculum changes to be sought.

Cost: The cost of such evaluation endeavors is low.

Effectiveness: Little information is available on the effectiveness of this specific intervention although evaluation is a rather standard part of goal setting and planning, activities shown by research to be present in effective schools.

D. Facilitating Interventions

In addition to the interventions described above for attaining one or more of the three specific objectives of quantity, quality and appropriateness, there are some additional interventions designated here as facilitating interventions. These additional interventions are not focused in and of themselves on a particular objective. They are potentially important, however, for making the above interventions effective.

In the cost-effectiveness analysis of these facilitating interventions, effectiveness will be judged in a somewhat different sense; their importance will be judged on the basis of what research has to say about the result of their absence as well as their presence. In other words, is their presence an essential requirement before an intervention has a high probability of success?

1. Improving Local Leadership

This category includes several means of providing the local school district leadership needed to initiate and maintain changes identified in the interventions above.

a. Increasing the number of science supervisors within local school districts. The intent of this intervention is to increase the number of supervisory personnel with direct responsibility for fostering improvement in science education. To whatever extent the interventions analyzed above are implemented at the local school district level, these science supervisors, along with principals, generally would be most directly responsible for making them successful.

Cost: The cost of this intervention is low/medium if one assumes that a district with 20,000 students has a science supervisor and this action calls for providing two such supervisors for each 20,000 students.

Effectiveness: The effectiveness of this intervention is difficult to judge because of the systemic nature of the situation with which we are dealing. To begin with, there is a substantial research basis for asserting that leadership at this level is necessary if the other interventions described above are to succeed. It is not clear, however, that this leadership must come from someone designated as a science supervisor. In principle, at least, this leadership could come from general supervisory personnel or from principals. On the other hand, the more diverse the responsibilities of a leader, the more likely it is that the specific responsibilities for one area, such as science, will receive low priority. In summary, there are a substantial number of important leadership responsibilities critical to the success of many of the above interventions, but it is not clear that these responsibilities necessarily must be exercised by someone designated as a science supervisor.

b. Weighting program development and implementation more heavily in the job descriptions of local school district science supervisors. The intent of this intervention is that science supervisors devote a larger portion of their time to the leadership functions important for program development and implementation as portrayed in many of the interventions described above. It is assumed that the science supervisor role, like other leadership roles, can be defined to focus upon true leadership or it can be defined to give attention more to routine duties having little leadership impact.

Cost: On the surface at least, this intervention costs little. In practice, however, it may have costs at many levels from the school board on down through the administrative hierarchy to the science supervisor. This assertion is made because supervisors generally cannot play this desired role unless supported by the general level of expectations within the district and by the behaviors of people at many levels. Assuming this support exists, there are other costs, such as for inservice training to help the supervisor develop the skills necessary to play this leadership role. There may be additional costs such as the cost of providing support staff to whom more routine duties can be delegated to free the supervisor for leadership activities.

Effectiveness: Like the previous facilitating intervention, the effectiveness of this one is difficult to judge because of the systemic nature of the situation. The intervention probably has large potential, but it would be naive to believe this intervention could be implemented easily independent of support at all levels within the school district including the board of education.

c. Weighting science program development and implementation more heavily in the job descriptions of general curriculum personnel. The intent of this intervention is similar to b above with the exception that the responsibilities under consideration are in the hands of general curriculum personnel having a broad range of responsibilities rather than in the hands of personnel whose primary responsibility is just science.

Cost: The costs associated with this intervention are essentially the same as those described in b above.

Effectiveness: The effectiveness of this intervention is essentially the same as portrayed in the analysis for b above, if the personnel have the necessary science background and experience needed to fill the role competently.

d. State or federal funding of local district plans for providing greater leadership in science education. The intent of this intervention is to provide external funding for locally developed programs of improving science education. Funds would be awarded on a competitive basis according to research-based criteria about the essential features of successful local endeavors of curriculam development and implementation, and improvement of instructional quantity and quality. Such endeavors typically would draw upon resources from outside the school district, such as personnel from a college or university or a consortium such as described in C.g. above if available, but the initiative would be at the local level.

Cost: Estimating the cost is difficult because it could be initiated at very low or very high expenditure levels. As an arbitrary figure, an externally funded endeavor could be supported somewhere within the range of \$2.00 to \$5.00 per student; thus it probably is a medium cost intervention.

Effectiveness: Again, estimates of effectiveness for this intervention are difficult to make. Examples can be found of local leadership development endeavors that have been highly successful and other examples can be found where little evidence of change is apparent. On the other hand, the extensive research results showing that local initiative and leadership are critical for the success of program improvement endeavors indicate the intervention should be pursued. Not all endeavors of this nature are successful, but without them substantial change is unlikely.

Three characteristics stand out as important criteria to be applied to this intervention. First, the plans pursued must be locally developed and an integral part of the district's overall plans for implementing change. Second, the plans must reflect the characteristics research shows to be important in educational change endeavors. Third, the plans must be long-term. There is little reason to think that a one-year endeavor of this nature would be very successful. Current research leads to the conclusion that such efforts must persist for approximately five years before significant changes become somewhat institutionalized on a district-wide basis.

e. Training for school board members with respect to science education. The intent is to provide training for school board members concerning the process of improving science education. Funds for this endeavor would be provided by federal or state sources. The assumption of this intervention is that long-term programs for initiating fundamental change must have the support of the top policy making boards. It also is assumed they need additional information about the situation and are desirous of having it.

Cost: This endeavor would take one day and, to facilitate travel, would be provided at regional locations within the state. The cost is low.

Effectiveness: By itself, this particular intervention may not produce much but as part of a broad-based systemic effort this endeavor, or some variation of it, may be critical if change is to be initiated and sustained. An alternative to this specific intervention is a similar activity on a reduced scale as part of the annual state school boards' convention.

2. Testing Programs.

This category of interventions includes means of promoting change through district-wide science testing programs. The thrust of these local interventions is not to expand the amount of testing or change the testing program per se. The intent is to change the nature of what is being tested in science so it is as consistent as possible with the curriculum of the school district. As a result, this collection of facilitating intervention is directed mostly at objective #3, i.e., making the curriculum as appropriate as possible, even though testing programs also may have an impact on the quantity and quality objectives. For purposes of this analysis, the extent of the district testing program is taken as a given; whatever that role, the focus is simply upon the content of the items.

a. Conducting awareness conferences and training sessions in test preparation for district testing personnel. The intent is to train local district testing personnel to better match the content of their tests to the school curricula. If the curriculum is to be changed, i.e., the content made more appropriate, district level science tests also must be changed because of their influence on the extent to which teachers will teach given topics. The proposed conferences and training sessions would inform the testing personnel of changes taking place in science instruction and provide them with training in how to write, or select from existing sources, test items appropriate to a particular science curriculum. Such conferences and training sessions could be conducted at the state level for district personnel, or if conducted at the national level, the audience could be either local school district personnel or state personnel responsible for state-wide testing in science.

Cost: If conducted at the state level for personnel from districts having their own district-wide tests, the number of participants in a state like Colorado would be relatively small, possibly representatives from 20 school districts. Assuming that some districts would have two testing specialists attending this conference, the cost estimates are based upon 30 participants. The cost is low.

Effectiveness. The effectiveness of this intervention in bringing about a shift in curriculum content is somewhat difficult to determine. The first question in this analysis of effectiveness may be whether or not the participants actually would change the content of test items as a result of attending the conference. In this regard, it would seem that their response would be highly dependent upon other actions being taken in their particular district for producing curricular change. If such change were underway, they would in all likelihood be quite receptive. On the other hand, if curricular change is not underway, they are unlikely to be receptive to changing tests and thus "get out in front" of the change process in their district.

Assuming that some curricular change is underway in a given district, and that the testing personnel are ready for change in test content also, there is considerable reason for optimism about the effectiveness of the conference in helping testing personnel change the content of the tests. Persons holding these testing positions generally have the testing expertise needed to capitalize upon the training. This analysis assumes that appropriate test items can be written or selected from other sources at a reasonable cost. Such action is the subject of the next category of interventions listed below.

b. Developing banks of appropriate test items and making them available to local district testing personnel. Developing test items is a time consuming and expensive process. As a result, even a commitment to preparing new tests as indicated above may not be sufficient to bring about change in testing programs in cases where district resources are limited. The intent of this intervention is to alleviate that problem by making available banks of appropriate test items. Although items emphasizing personal applications of science knowledge and the use of science in addressing societal issues occasionally are found, no extensive collection of such items is known to exist which could serve as an item bank. The intent of this intervention is to overcome that lack and facilitate district attempts to develop more appropriate testing.

Cost: The total cost of developing a bank of 300 items is relatively low. Once this development work is completed, the test items could be placed in one or more existing item banks from which school districts could draw. The costs of developing the total tests is assumed to be part of the on-going process in a given school district.

Effectiveness: The effectiveness of this intervention is expected to be high where curriculum change toward more emphasis upon the applications of science is underway and district tests are constructed locally. This assessment of effectiveness also assumes an awareness of the fact that these items are available.

c. Holding an awareness conference for publishers of tests used in district-wide testing programs. The intent is to make publishers of tests aware of curricular changes underway and encourage them to develop appropriate test items emphasizing any new orientation, e.g., the applications of science. It is assumed that these publishers have the resources for doing their own test development; the intent of the conference is to encourage them to use these resources to develop tests as consistent as possible with emerging directions in science instruction.

Cost: Assuming that representatives of 10 publishers are involved in the conference, the costs are very small.

Effectiveness: Assuming the intent of this intervention is to encourage these test publishers to stay current with curricular change, and not expect them to be a vehicle for promoting change, there is every reason to expect that the participants would be responsive to changes underway in the schools. Publishers of such material respond to the demands of the marketplace as the primary determiner of the type of tests they prepare. But a second factor is a seeming inertia and slowness to change. The conference could be considered effective if the typical time delay in such change were shortened as much as possible and even one publisher were convinced to prepare a science test which was consistent with the cutting edge of curricular change. Recognizing a potential market for such tests is the key to action by a publisher. Having a suitable test available for those districts seeking it, and thus eliminating a barrier to educational change, is important.

d. Informing established citizen accountability committees in local school districts of the need for improved testing and encouraging them to use their influence to make appropriate modifications. The intent is to inform influential local citizen groups, who often deal with the results of district testing programs, of the need to use appropriate tests. The focus of this information would be curricular changes underway and the need for having consistent testing measures. Information could be disseminated to such people via publications and an awareness conference.

Cost: Based on an estimate of 2,900 accountability committee members in the state of Colorado, the cost of developing, printing and distributing the needed materials and conducting an awareness conference for the chairpersons of such committees in each of the 181 school districts in Colorado would be low.

Effectiveness: By itself this intervention could be expected to have little impact. If done in association with a series of coordinated interventions all focused upon the same kind of curricular change, it may be influential in the overall attempt to bring about change.

3. Public Education

Since major changes in public school programs require public support, a category of potential facilitating interventions includes mechanisms for informing the general public about the issues involved in science education and providing science and technology information needed to make informed decisions about science and technology education issues. Some of these interventions go further, becoming overt attempts to persuade the public through advertising that science and technology education need improvement an a larger role in the schools. Examples of these interventions include the following.

a. Various forms of media advertising to promote the idea of students taking more courses in science. Advertisements could be prepared by professional science or education associations and provided to the media to use as public service advertisements. In a manner similar to promotions of the President's Council on Physical Fitness, these advertisements could advocate that all students take more science and encourage the public to provide the resources and other support needed for the schools to expand their science endeavors. An example of this advertising is recent radio "spots" from the American Federation of Teachers.

Cost: To the extent that public service announcement time is available for these advertisements, the cost is relatively low. Essentially it would be the initial cost of preparing the advertisements. A possible source of funds for this activity is donations from scientific and technologically oriented industries. In addition to the development of such advertisements by their advertising departments, such firms may wish to donate a certain amount of advertising time or space as a public service.

Effectiveness: It is difficult to judge the effectiveness of this type of campaign. An example of an analogous campaign is the one conducted by the President's Council on Physical Fitness and Sports. Their 30-second television spots on NFL telecasts in 1976 resulted[46] in nearly 14,000 written requests for information on school programs.

b. Science television programs for the public. The intent is to provide for the general public, both children and adults, more science programs which develop a broader understanding of science and thus generate a broader base of support for science education in the schools. Such programs would be offered on network television, cable channels, and public stations. While such programming has expanded in recent years, this intervention is an attempt to expand it even further.

Cost: The total costs are large. Production costs for a standard, prime-time, one-hour science program such as NOVA or Nature are about $400,000 per hour[47] and air time is additional. On a per person basis, however, the costs are quite modest.

Effectiveness: Assessing the effectiveness of this science programming for the purpose stated here is essentially impossible. In addition, there are so many other criteria used in determining what programs will be aired that, by itself, a desire to promote science education will not likely cause science programming to be broadcast.

c. Adult education courses for the public on science and technology. The intent is to broaden public understanding of science and technology and thus generate greater support for science education in the schools. Thus, the purpose of this intervention is essentially the same as b above.

Cost: Most adult education courses of this nature are offered on a "pay their own way basis" by the continuing education units in colleges and universities and to some extent by private educational organizations. To whatever extent one wishes to promote such offerings beyond the level currently sustained by people's willingness to pay to attend, one would have to reduce the cost of attending. We have little more than guesses as to how much reduction in cost would be necessary before enrollments would be increased substantially. The maximum cost would be the total cost of the courses, thus making them free. In that case, a reasonable estimate of cost is the standard tuition.

Effectiveness: Even if the number of offerings of this type were increased substantially and large numbers of people participated in these courses, it would be extremely difficult to assess the extent to which the increased public knowledge had any effect upon the public's interest in more and better science education in the schools.

Summarizing the Cost Effectiveness Information for Single Interventions

In the previous pages, each of the specific interventions has been described in terms of its cost and effectiveness as a single intervention. For each, a specific cost has been given, along with a discussion of its potential effectiveness as a single intervention. This effectiveness has been presented in somewhat less quantitative language than costs since the potential of an intervention often depends on the particular circumstances under which it is initiated or the manner in which it is used.

When combining cost and effectiveness information to determine an intervention's cost-effectiveness, attention also must be given to the extent to which it can be used. For example, a particular intervention may cost little to implement and it may be highly effective within a certain range, but there simply may be a very short range in which it can operate. A specific example is reducing the number of "non-instructional activities" scheduled in the school week. If only 4 percent of the current week is so scheduled, there is little opportunity to increase the time scheduled for instruction, even though the little gain available could be acquired at small cost. The worth of a given intervention depends on a variety of factors.

Cost and effectiveness information is combined for each single intervention and presented below in four matrices (Figures 2, 3, 4, and 5)--one for each of the four major objectives: quantity, quality, appropriateness, and facilitation. In each matrix, each specific intervention is given a location designated by the letter or number and letter combination used for it earlier in this report. This location in the matrix gives its relative cost and effectiveness compared to the other interventions in the matrix. No scale is given on either axis of the matrix simply because it may imply more precision in the determination of cost or effectiveness than is appropriate for a given action. The location of each intervention on the horizontal axis is based on the cost information presented in Table 3 as compared to the other interventions for that objective (the cost scale for each of the four matrices is not the same and the scales are not necessarily linear). Similarly, the vertical axis portrays relative effectiveness. In both cases, the axes are divided into thirds designated as low, medium, and high.

Because of the large variations in cost and effectiveness of the interventions, and the fact that choices must be made among the possible interventions, only those falling in certain sectors of the matrices probably should be considered. First of all, any intervention falling in the low-cost/high-effectiveness sector should be given immediate attention. Unfortunately, they are few in number. Second priority goes to those interventions falling in the medium-cost/high-effectiveness or low-cost/medium-effectiveness sectors. As a third priority, consideration may be given to the medium-cost/medium-effectiveness sector. As a single intervention, those falling in one of the other three sectors should be given low priority. One caution must be given in this regard, however; an intervention that does not

Effectiveness	Cost: Low	Cost: Medium	Cost: High
High	e		c c'
Medium	d	a b	
Low	f	g	
Unknown			

Figure 2. Cost-Effectiveness Matrix for Single Interventions for Objective #1: Quantity.

(See page 16 for a description of each of the interventions designated in the matrix.)

Effectiveness	Cost: Low	Cost: Medium	Cost: High
High			
Medium	3b, 4g, 2f	1b, 1d, 1e, 1a, 1c, 2h, 4j	3a, 2i, 6g
Low	4h, 2b, 4f, 1f, 6f, 4d, 2e, 4c, 4e, 4a	2c4i, 5a, 1h, 2g	2a, 4k, 4b, 6e
Unknown	6a, 6b, 6d, 6c		3c

Figure 3. Cost-Effectiveness Matrix for Single Interventions for Objective #2: Quality.

(See pages 16-18 for a description of each of the interventions designated in the matrix.)

Effectiveness	Cost: Low	Cost: Medium	Cost: High
High	i		
Medium	e a a´ d b´ h b		
Low	g f j		
Unknown			

Figure 4. Cost-Effectiveness Matrix for Single Interventions for Objective #3: Appropriateness.

(See page 18 for a description of each of the interventions designated in the matrix.)

Effectiveness	Cost: Low	Cost: Medium	Cost: High
High			
Medium			
Low	1b, 1d, 1c, 2d, 2b, 1a, 2a, 1e, 2c		
Unknown	3a 3b	3c	

Figure 5. Cost-Effectiveness Matrix for Single Interventions for Facilitation.

(See pages 18-19 for a description of each of the interventions designated in the matrix.)

look very attractive as a single intervention may be a critical component of some combination of interventions to be discussed later in this report.

While a major theme of this report is that interventions should not be viewed singly but in combinations, some comments are in order regarding to the single interventions displayed in the four matrices for the four objectives as follows.

Quantity. In the matrix for single interventions for Objective #1: Quantity (Figure 2), one intervention is found in the low-cost/high-effectiveness sector, namely increasing the class time devoted to instruction. There is research to indicate that this intervention will work and the cost of the inservice education needed to bring it about is quite low when prorated over a five-year period. Even if additional supervisory support were utilized in addition to the inservice education, the cost would remain very low compared to that of other interventions under consideration for increasig the quantity of learning time. A second priority intervention is increasing homework for students. Lower in effectiveness and higher in cost than the former intervention, it still deserves consideration. Finally, consideration can be given to the medium-cost/medium-effectiveness category in which are found the interventions which would cause students to enroll in more science courses. While substantially higher in cost, particularly for the students, the increase in science learning is substantial and also quite certain given an appropriate curriculum. They are worthy of consideration.

Quality. No interventions are found in the low-cost/high-effectiveness sector of this matrix (Figure 3). The low-cost/medium-effectiveness category, however, contains several interventions including better supervision and evaluation of instruction in the classroom, improved teacher recruitment and placement, the initiation of improved instructional practices such as mastery learning, and certain forms of inservice education specifically coordinated with other local development work or improved teacher evaluation procedures. While considered here as single interventions, many of them imply some coordination with other initiatives; not surprisingly, many of them will arise later in this report in a discussion of combinations of interventions. At the next level of priority in this matrix is the medium-cost/medium-effectiveness sector which includes several interventions related to teacher education. While they are clearly long-term rather than short-term prospects for improving science education, the role of the teacher is so central to quality education that these interventions should not be ignored.

Appropriateness. While the scale used for costs in this matrix (Figure 4) could have been arranged to spread the interventions across the whole matrix in the cost dimension, the costs of all of the interventions in this category for improving the school curriculum are so low on a per pupil basis (assuming type of local curriculum development is selected in accordance with district size) when compared to the quality interventions described above that they were displayed in a manner that indicates this very low per pupil cost. The high effectiveness intervention in this matrix, new standards for textbook adoption, does not pertain to Colorado, since it does not have a state textbook adoption process. It pertains only to a very few states where the population is large enough to be a significant market force and where the process could be used to insure that the textbooks would in fact have to change substantially. The interventions included in the medium-effectiveness category all involve mechanisms for developing new curricula; there is a variety of approaches. A crucial question that must be raised in connection with development of new curricula, however, is whether or not there is a process by which these new curricula will be implemented in the schools. Though not specifically addressed here in the context of curriculum development, this issue will arise again when consideration is given to a combination of interventions.

Facilitation. This fourth objective deals with interventions which make it possible to bring about change in the schools; they should be viewed as interventions which make possible the actions described in the three matrices above. In that context, many of these actions may be critically important and essential, if the other actions are to succeed. For purposes of this matrix (Figure 5), however, these interventions are considered on the basis of their effectiveness as interventions in and of themselves. In this context, it is not surprising that none of them appear in the priority sectors.

Chapter 4. Combinations of Interventions: An Imperative for a Systemic Problem

Several references have been made in the previous chapters to the systemic nature of the school situation in which improvement is being sought. This perspective highlights the inadequacies of examining the situation in terms of single, independent interventions. An adequate analysis must account for the power of combinations of interventions (the effects may not be simply additive) and interactions which may occur among the interventions.

If it is granted that the situation must be analyzed from the perspective of a combination of interventions, one is still left with the question of what conceptual framework should be used to organize this analysis. Fortunately, the last two decades of educational research have yielded numerous findings which, when taken together, can provide the needed conceptual framework. While such studies are numerous and diverse in topic, there are three streams of research which have been particularly productive and have special potential for providing the guidance needed in this analysis. These three include research on (1) school effectiveness, (2) implementing educational change, and (3) the role of school principals. Each of the three will be examined to identify major findings and implications of particular note for this analysis.

In view of the extensive nature of this body of literature and the existence of several extensive and carefully done reviews of the research in these areas, existing reviews have been used as the basis for developing the conceptual framework described in this chapter. Four in number, they include the following.

Gene E. Hall and Susan F. Loucks, "A Developmental Model for Determining Whether the Treatment is Actually Implemented," American Educational Research Journal, Summer 1977, Vol. 14, No. 3, pp. 263-276.

Michael Fullan and Alan Pomfret, "Research on Curriculum and Instruction Implementation," Review of Educational Research, Winter 1977, Vol. 47, No. 1, pp. 335-397.

K. A. Leithwood and D. J. Montgomery, "The Role of the Elementary School Principal in Program Improvement," Review of Educational Research, Fall 1982, Vol. 52, No. 3, pp. 309-339.

Michael Cohen, "Instructional Management and Social Conditions in Effective Schools," in the Fourth Annual Yearbook of the American Educational Finance Association, School Finance and School Improvement: Linkages in the 1980s, Allan Odden and L. Dean Webb (Eds.), Cambridge, MA: Ballinger Publishing Co., 1983.

Although these reviews are focused mostly upon the direct findings of the research on these topics, there are some instances in which the reviews extend beyond simple reporting of research findings to making extrapolations from the data to various school situations. This is a positive feature of these reviews; even though these extrapolations are to some extent speculations about the implications of the research findings, they provide valuable insights as to the implications of the research for educational practice.

In utilizing this research, however, one must also recognize some limitations. The school effectiveness research (but not the implementation research) has been done mostly at the elementary level and is focused mostly upon reading and mathematics skills.

> While the secondary school studies are generally consistent with the findings from the elementary level, our knowledge base is much stronger at the elementary grades. Because secondary schools generally differ from elementary schools with regard to size, variability in student backgrounds, organizational complexity, goal diversity, subject matter offerings, and developmental level of the students, the application of findings from elementary schools to secondary schools needs to be made with caution.[48]

While these limitations must be recognized, the school effectiveness research literature is quite extensive and provides a substantial basis for making decisions as to the appropriateness of various interventions for improving education.

In the following sections of this chapter, attention will be given first to research on the character of effective schools, and secondly to research on the nature of successful processes for implementing educational change. Finally, attention will be turned to the research on the role of principals since this factor is shown in the former two categories of research to be unusually important for both effective schools and for implementing educational change.

Research on Effective Schools

Before examining the characteristics of effective schools as identified by research, it is well to note two general items that appeared in this research literature. First, according to Cohen, "comparing the schools on the resources that are available to them is not as meaningful as comparing the schools on how well they organize and use their available resources. . . ."[49] In other words, just providing additional resources to the schools is not the answer to increased effectiveness. Particular attention must be given to how these resources will be used, for what purpose, and by what means. Secondly, note that some practices or variables pertain to the classroom level, while others pertain to the school level. A multi-level perspective must be maintained. Later in this chapter, this multi-level perspective will be extended to the school district, state, and national levels as well.

In his 1983 review, Cohen identifies three themes in the research literature on effective schools. The characteristics of effective schools can be grouped within the following categories: (1) effective classroom teaching practices, (2) coordination and management of the instructional program at the building level, and (3) shared values and culture among both students and staff. These three themes will be elaborated upon below in considerable detail based upon the review by Cohen.

Effective Classroom Teaching Practices

The effective classroom teaching practices shown by this research pertain to (1) teachers' expectations of students and the role teachers occupy, (2) the classroom management practices followed, (3) an active and direct form of instruction, and (4) careful attention to a maximum amount of academic learning time for students. With respect to teachers' expectations and their role definition,

> Effective teachers believe they have the capacity to affect the learning of students. They take responsibility for teaching, and if necessary re-teaching, to achieve student mastery of the material. They are task oriented, business-like, clear in their instructions to students, and in general take charge by monitoring behaviors, choosing instructional activity and developing a classroom with a distinct focus upon academic matters. There is a sense of purpose and students are held accountable.[50]

These high expectations are encouraged and their attainment fostered by effective classroom management. These practices "keep students engaged in academic tasks, and minimize classroom time lost due to disruptions, transitions, and other procedural tasks. . . . Effective teachers use well organized and prepared lessons, which enable them to move through instructional activities at a brisk pace."[51]

These high expectations and classroom management practices are used in support of yet a third characteristic, namely an active, direct form of instruction by these teachers. This form of instruction is not highly individualized and does not have a substantial discovery learning flavor. There are specific goals and they are diligently pursued.

The fourth practice is careful attention to the fullest use of academic learning time. The time allocated for instruction is important. "Teachers who allocate more time to a particular content area have students with higher achievement in that area, compared with teachers who allocate less time."[52] Another characteristic of these effective teachers is that a high percentage of the allocated time is actually engaged in learning. "The higher the engaged time, the higher the achievement."[53] It is also important to note that there are major variations in engaged time among teachers. Studies have shown these engagement rates to vary "from as low as 50 percent to highs which approach 90 percent."[54]

School Level Instructional Management and Coordination

In addition to the characteristics of individual classrooms, effective schools are characterized by two building-level matters. First, Cohen indicates that the curriculum and instructional program is "tightly coupled." In other words, goals, objectives, instructional content and activities, and the measures of performance are "carefully aligned." The whole school takes on a character consistent with the individual classroom practices cited earlier. There are uniform time allocations within the school, shared goals which carry more weight than individual teacher goals, common expectations among teachers and other professional staff, and testing is both important and related to the instruction.[55]

Because of its importance, the concept of principal leadership is developed in some detail in a later section of this chapter. In general, however, it can be said that the effective principals (1) have a strong goal orientation, i.e., they emphasize achievement, set goals, develop performance standards for students, and express optimism about reaching these goals; (2) take responsibility for organization and management of instruction, including regular observation of teachers, assistance with the problems of instruction, and provision for staff development; and (3) buffer teachers from interruptions, including limiting classroom intrusions, seeing that materials and supplies are available, and handling discipline effectively.[56]

Shared Values and Culture

Effective schools are characterized by shared values and culture including such key elements as (1) a strong sense of community, (2) commonly shared goals, (3) high expectations for students and staff, and (4) mechanisms for maintaining common commitment to goals.[57] In particular, they share two important work norms. First, collegeality is important; "the work of teachers is shared work." Also, there is an expectation that improvement is continuous and never ending.[58]

Research on Implementing Educational Change

The change under consideration here is curriculum change, including changes in subject matter, instructional materials, organizational structure, and the role or behavior of teachers. In studying the process of bringing about such curriculum change, researchers also give attention to the professional staffs' knowledge and understanding of the various components of a particular innovation and the degree of value internalization that takes place concerning such changes.

The process of introducing an innovation or curricular change is complex; the extent to which proposed innovation actually occurs varies considerably and generally is quite limited. In one study, for example, it was found that "the overall quantity of innovation effort was very low, about 16 percent; that is, teachers displayed behavior congruent with the innovation about 16 percent of the time." On a five-point scale of quality, "the average staff scores for the twelve criteria range from a high of 2.7 to a low of 1.3 with ten criteria below 2.0." There are decided variations in the extent to which innovations are implemented in schools and the extent to which particular components of an innovation are implemented.[59] There are different levels of use of an innovation; the actual presence of an innovation can be established as a fact only by assessing its use directly.[60] Research also establishes that student achievement is related to the extent to which an implementation actually occurs.[61] Research establishes rather clearly that the degree of actual implementation of an educational innovation is generally much less than described in the intended plans.

An obvious question is why attempts to implement educational change so often fail.

> The main problem appears to be that curriculum change usually necessitates certain organizational changes, particularly changes in the roles and role relationships of those organizational members most directly involved in putting the innovation into practice. That is, role occupants are required to alter their usual ways of thinking about themselves and one another and their characteristic ways of behaving towards one another within the organization.[62]

Research clearly establishes that the most difficult aspect of innovation is bringing about changes in the roles of people. In contrast to role changes, program and structural changes are relatively easy.[63] One aspect of this difficulty may be the inability of principals and teachers to understand the process in which they are involved. Research shows principals do not have a good knowledge of the degree to which an implementation is occurring in their school. Similarly, the majority of teachers apparently have difficulty identifying the essential features of innovations.[64]

The complexity of the implementation process, particularly with respect to changing the roles of people, makes it difficult to prescribe ahead of time the exact form an innovation eventually will take. A mutually adaptive process involving the innovation, the user of the innovation, and the institutional setting must occur.[65]

A characteristic of the innovation process particularly pertinent to this analysis is the need for several factors in combination in order to bring about an important change. Research shows that it is the combination and interaction of a variety of factors that constitute the essential ingredients for implementation of an educational change.[66] "It is important to note that these factors are interactive in the sense that they may be mutually reinforcing over time. The presence of any one without the others would probably limit if not eliminate its effectiveness [emphasis added]."[67] Having identified the importance of the combination and interaction of interventions, attention can be turned to specific policies and practices necessary for producing change.

Policies and Practices for Implementing Educational Change

The following description of the policies and practices which research shows to be effective in implementing educational change are largely organized within categories developed by Cohen. The first five of the following major categories are his, although information obtained from other reviews is described below within this general framework. These five categories of policies and practices for producing behavioral changes at the local level include (1) school improvement programs; (2) various strategies for increasing the time devoted to instruction; (3) processes for selecting, training, and developing principals; (4) mechanisms for more tightly focusing or coupling the curriculum; and (5) structural changes based on school values and culture. In addition, attention will be given in a sixth category to central school district policies and various socio-political factors that influence the process.

School Improvement Programs

An important local level step is initiating school improvement programs. Under such programs, an external agent works with the school staff on implementation. Key features of such school improvement programs include the following: (1) the school building is the unit of change, (2) the process focuses on problem identification, (3) solutions come from a combination of research findings and staff judgment, (4) specific plans for implementation are developed locally, and (5) the plans are then initiated.[68] Although extensive research literature is not available to back it up, it appears that "participation in the innovative process by those who are expected to implement the new program is widely thought to be an effective strategy, and of paramount importance."[69] The manner in which such school improvement programs are conducted may be critical.

Strategies for Increasing Instructional Time

A variety of strategies can increase both allocated and engaged instructional time. Among practices advocated for increasing allocated time are (1) increasing the length of the school day or school year, (2) increasing the amount of homework, (3) establishing district policies on minimum allocated time, (4) auditing the use of classroom time, and (5) developing goals for a building or a district on the use of time. Potential strategies for increasing engaged time include (1) inservice training, (2) improved school discipline policies and practices, and (3) attendance policies and practices which encourage pupil attendance.[70]

Although inservice training will appear again in this review of research findings, it probably is well to note at this point that the form of inservice training is an important factor. "It appears that intensive inservice training (as distinct from single workshops or preservice training) is an important strategy for implementation."[71] The purpose and form of inservice training must be considered; inservice education cannot simply be considered in a global sense without attention to its distinct forms.

Principal Selection, Training and Development

Since research shows principals to be a most prominent variable in the implementation process, careful attention must be given to how they are selected, trained, and assisted in their professional development. Based on these research findings, it would appear that policies and practices for implementing educational change must give prominent attention to (1) improved selection procedures which give major attention to the instructional management capabilities of prospective candidates for the position, (2) preservice training focused more on building-level instructional management skills than typically is found in current programs, and (3) improved inservice education for principals focused on building-level instructional management competencies.[72]

Tightening the Focus of the Curriculum

Because of the importance that the research on effective schools gives to a tightly focused curriculum, policies and practices for implementing positive educational change must include attention to such curriculum characteristics. Cohen argues that these mechanisms could well include the following: (1) district-wide testing programs that focus the curriculum on important goals; (2) school-wide planning endeavors focused "on a limited set of instructional goals"; (3) district-wide curriculum development; (4) district-wide policies on high school graduation, promotion, instructional time, and expectations of high student achievement; and (5) plans and goals which have been agreed upon jointly at both the building and district levels.[73] Other research provides further information as to the nature of such endeavors. "In our review of research, there are two characteristics of innovation that stand out as being related to implementation. These are the explicitness or plans for explicitness associated with the innovation and the complexity or degree and difficulty of change required by the innovation."[74] The research also highlights the importance of feedback mechanisms within such endeavors. This term refers to "the nature of the interactive network during implementation. . . . It is somewhat global . . . . refers both to feedback structures and to norms supporting open feedback, as well as to interaction involving several constituencies such as teachers, consultants, administrators, and ideally students, parents and others. . . . Most research we examined cites the absence of the feedback networks during implementation as a critical problem."[75] With respect to testing programs, it should be noted that studies of actual practice in schools show a relatively low overlap of the content of tests and textbooks; it ranges between 14 and 50 percent. There clearly is substantial room for improvement in this aspect of the process of tightening the focus of the curriculum.

Structural Features to Shape School Values and Culture

Research shows that the values and the culture shared within a school are important determiners of school effectiveness. There should be mechanisms for increasing the extent to which such values and culture are shared within a school. (1) Efforts should be made to increase building-level autonomy even if it requires a reduction in the degree of uniformity found within a school district. (2) Provision should be made for as much parental choice as possible concerning their children's education. (3) Time must be provided for teachers to engage in "shared work and collective decision making." That is, greater planning time must be provided by any of a variety of mechanisms. Each of these three changes has the potential of developing a stronger common set of values within a school. Research has shown this commonality of purpose and values to be important for effective schooling.[76] The third of the three factors mentioned above with respect to values and culture is of particular importance. Research shows this shared work and decision making is related significantly to measures of implementation.[77]

Central School District Policies

By and large, the above five categories are mostly building-level policies or practices, though several are a combination of building and district level. Additional mechanisms can be pursued specifically at the district level. Research shows typical district-level policies do not strongly influence implementation, primarily because they do not address the most critical factors. Among possible changes in typical current practice are the following.

> First, instead of promoting specific innovations, central policy makers should be emphasizing broad-based programs and providing corresponding support for local development of specific forms of implementation, thereby facilitating clarity and explicitness of programs on the part of users. . . . Second, local experimentation should be encouraged during implementation to develop variance of innovations. . . . Third, evaluation of innovative projects at least during initial implementation should be directed toward facilitating implementation in local system capabilities. . . . Fourth, and closely related to the previous points, the incentive system for implementation would have to be drastically altered at all levels. There is one finding that stands out in our review, it is that effective implementation of social innovations requires time, personal interaction and contacts, inservice training and other forms of people-based support. Research has shown . . . there is no substitute for the primacy of personal contact. . . .[78]

District policy makers also should give particular attention to a distinction found in the RAND studies of educational innovation. They "identified two contrasting types of adoption process that characterized the numerous projects they investigated. They termed these opportunism and problem solving." Opportunism describes projects in which little local commitment was evidenced and the endeavors were largely a response to the possibility of receiving additional funds. Problem-solving projects were those which had locally identified need. The problem-solving projects led to "greater changes as a result of the innovation."[79]

Research on the Role of Principals

Considerable research has been done on the role of principals as it relates to their effectiveness in increasing student learning within a school or implementing curricular change. The commonality found in both the research on school effectiveness and the research on implementing change concerning the importance of the principal requires that it be examined in greater detail here.

To understand the principal's role, one must recognize that it is inherently complex and ambiguous. Central school district administrators often see principals as middle managers rather than educational leaders. These central administrators tend to be conservative about change and want to initiate it themselves rather than having it begin at the school level. Since research shows that such change is most effectively initiated at the building level, it is obvious that the principal's role has some inherent conflicts. In addition, the principal faces problems arising at levels below him or her. Research shows that among the problems faced by principals are: (1) a lack of knowledge and professional skills on the part of teachers, (2) a lack of teacher motivation to make significant changes, and (3) constraints introduced by collective bargaining and union contracts.[80] In addition, there is a pervasive norm of teacher autonomy in the schools. Attempts to introduce shared planning and work (important factors according to the research literature) are in opposition to this norm. A further difficulty is that principals have "minimal direct control over those aspects of classroom life that teachers find most rewarding."[81] The principal seeking to increase the effectiveness of his or her school, or seeking to introduce significant educational change, faces numerous difficulties.

While the typical principal (in contrast to the "effective" one) provides leadership which is largely administrative, the effective principal also must act as an instructional leader. Both kinds of principals must deal with similar routine matters. Research shows, for example, that both give significant attention to making adequate resources and materials available to teachers. With respect to routine matters, however, effective and typical principals differ substantially in the efficiency with which they handle them. Typical principals report being drowned in a sea of "administrivia." Apparently effective principals handle the routine matters efficiently and move on to spend considerable time in matters of true educational leadership.[82]

Effective principal behavior can be examined in more detail within three major categories pertaining to (1) goals, (2) factors affecting student achievement, and (3) strategies employed to do their job.

Goals

Specific goals play a prominent role in the work of effective principals. In addition to being prominent, they are focused upon particular priorities. "Effective principals place the achievement and happiness of students first in their priorities."[83] Students have the highest priority. A key point is "the central role of goals and their use in distinguishing effective from typical principals. . . . Effective principals use the process of planning and goal formulation to encourage participation by teachers in decision making and actively solicit their opinions. . . . The goals themselves serve to clarify expectations for the implementation of program innovations."[84] It is hard to overemphasize the importance of goals as described here; their importance is prominent throughout the research literature.

Factors Affecting Student Achievement

Effective principals give high priority to those factors which influence student achievement. They use objectives as a focus for instruction and a basis for seeking improvement in learning. In addition, they make time-allocation decisions based upon specific instructional objectives. Attempts are made to bring about greater coordination of goals and instructional methods. Curriculum development work they initiate and promote is focused upon instructional goals. Since goals and objectives are prominent in each of the statements just cited here with respect to the work of effective principals, the importance of the previous discussion on goals becomes even more apparent.

In addition to their focus upon goals, effective principals are concerned about selecting and developing competent staff. They are willing to take the time necessary to perform these responsibilities. Effective principals also have a particular view toward the various sources of funds available to them. Whether these sources be government agencies, special funds from their own school board, or externally funded projects, effective principals view them as possible sources of funding for their own goals.[85]

Strategies

"Effective principals were exceptionally able strategists. They could identify effective ways of achieving their ends."[86] These effective strategists have many things in common as described below.

The strategies are at least partially derived from several strong beliefs which effective principals shared. They have a strong belief in the goals they hold for their schools and are convinced the school system can tolerate enough diversity that they can move ahead and take whatever steps are needed to accomplish the goals in which they so strongly believe. These effective principals also are committed to communicating their goals and selling their ideas to the community and the staff, including the superintendent and whoever has control over needed financial resources. Effective principals also are willing to share decision-making power and delegate authority, but it was done within a framework which they establish. They set up structures to foster teacher participation; teams are established to address curricular problems and regular and frequent staff meetings are the norm.[87] Effective principals encourage their staff to set their own goals, including goals for their personal professional development as teachers.[88]

Effective principals encourage professional development in their school, work with teachers on issues identified during classroom observation, and arrange for and encourage teachers to participate in structured professional development activities initiated for their school. In contrast, less effective principals have little or no participation in teacher inservice education activities. Effective principals assist staff members in gaining the resources needed to foster the teacher's own professional development.[89]

Effective principals collect a lot of information (much of it informal) about what is going on in their schools. They closely monitor student progress by reviewing test results, investigating cases of slow student progress, and discussing with teachers the various issues involved.[90]

Effective principals are concerned about the needs of teachers in contrast to typical principals who often do not consider the values and emotions of teachers. Effective principals evaluate instruction, and help teachers find the non-teaching time required to improve their instruction.[91]

"Effective principals are very active in facilitating communications between the school and community." Communication at all levels is important; it is focused upon attaining specific goals, not just fostering communication and positive relations for their own sake.[92]

Leithwood and Montgomery summarize the information on effective principals in three items. (1) The key goal of effective principals is promoting student cognitive growth. (2) These principals work toward this goal "by attempting to influence a complex set of classroom-based and school-wide factors." (3) Cooperative interpersonal relationships are viewed as "an instrument to goal achievement, not an end in its own right."[93]

Implications of This Research

While the details of this analysis of the research on effective schools, mechanisms for implementing curricular change, and effective principals also will be used in selecting combinations of interventions in the next section of this report, there are three major implications to be identified here as generalizations upon which the further analysis will be based.

First, the importance of a combination of interventions is clear. Specific interventions cannot be examined in isolation. Particular combinations must be utilized based upon what research says about appropriate combinations and their interactions.

Second, the completeness of a particular combination of interventions may be critical. The research indicates that the lack of a particular intervention from a given combination may be sufficient to eliminate attainment of the goals to which the combination is addressed.

Third, whatever combination of interventions is selected, it must be based upon a multi-level perspective. Some interventions must be introduced at the classroom level, some at the school level, and some at the district level. In addition, whatever interventions are considered at the state or national level must give full and proper attention to the various lower levels at which research indicates the interventions can be effective.

In addition to these generalizations, there are specific actions which are prominent within the three streams of research.

Integrating the Three Streams of Research

Taken together, these three streams of educational research reinforce the importance of several kinds of action at the building and school district level. They are summarized in the following lists:

Principal's Actions

- o Develop school-wide goal setting and explicit planning for change.
- o Give high priority to supervision and evaluation of instruction.
- o Develop procedures for shared work.
- o Provide support services for teachers in implementing new curricula.
- o Use great care in selecting new teachers.

- o Develop feedback mechanisms for receiving information from within the school.

- o Initiate a school improvement program.

District Policy

- o Establish policies on graduation, promotion, instructional time, and student expectations.

- o Establish an appropriate policy on school autonomy.

District-Level Actions

- o Carefully select new principals on the appropriate criteria.

- o Provide inservice education for principals focused upon (a) leadership for effective schools and (b) developing goals and participation.

- o Support the development of innovation at the building level.

- o Make the testing program congruent with instructional goals and the curriculum.

- o Initiate and support curriculum development at both the district and building level.

- o Provide inservice education for teachers at the district and building level focused upon (a) teachers' expectations and roles, (b) classroom management, (c) active and direct instruction, and (d) learning time.

Combinations of Interventions

With the review of research on effective schools and implementing educational change as a foundation, attention again can be turned to the eleven categories of interventions and the most effective combinations of selected actions from these categories. Each category of interventions will be considered in the light of its possible role in a total collection of intervention focused upon improving science education in a systemic manner.

Because of this systemic viewpoint, the effectiveness information provided for each single intervention must be reappraised in light of its potential interaction with other interventions. As a result, the effectiveness information may vary considerably from that provided for singl interventions, even though the cost information is still largely valid and n subject to significant change other than as two interventions overlap to suc an extent that it is cheaper to do the two in combination than singly.

Within each of the categories, its overall importance will be addressed along with identification of specific individual interventions and recommendations for action. Specifically, in each category attention will be given to (1) the degree of interaction among interventions, (2) the level or levels (national, state, local district, building, or teacher) at which the intervention should be initiated, and (3) the time frame (long term or short term) in which the intervention can be expected to be effective.

Objective #1: Quantity

Increasing Student Requirements. The value of innovation in this area is quite certain; if the amount of learning time is increased, an increase in learning is almost sure to follow. Innovations in this category appear to differ from the other categories in an important regard--they are less dependent for their success upon being done in combination with other interventions. The systemic nature previously mentioned so frequently cannot be ignored, but these interventions are not as interactive as most others. They also are shorter term than some others; once initiated, most interventions in this category can be expected to influence learning quite rapidly. Finally, it should be noted that there are interventions in this category which can be approached at several levels; some, such as increased engaged learning time and increased homework, can be initiated at the classroom level while others, such as increasing the length of the school year, can be initiated only at the district or state level.

Because this category of interventions is not very interactive, the analysis presented earlier for single nterventions still largely applies when discussing combinations. Increasing engaged time, i.e., increasing the amount of class time actually used for instruction, probably is the most cost-effective. The cost of acquiring is very small, even if a much greater amount of inservice education and supervisory help is needed to implement the intervention than estimated in this analysis. The cost of increasing homework also is relatively low, at least in terms of expenditures of tax monies. It also is worth pursuing.

Increasing science course requirements, either through graduation requirements or college admission standards, is an additional viable approach, but in terms of cost-effectiveness, probably only should be considered as additional steps to be taken after increasing learning as much as possible through greater engaged time and more homework. This intervention should not be initiated, however, without parallel attention to the interventions related to the appropriateness objective.

If one wishes to increase the quantity of learning time for science even further, the cost probably increases dramatically. Additional increases may require such measures as increasing the length of the school day or the school year; in this case the cost is great. There is little doubt that these measures will increase learning, but our society must be willing to pay the price involved.

Objective #2: Quality

This objective has several categories of interventions, some of which are quite interactive with other categories and some which are not. Although there are variations, most of these interventions are fairly long-term in nature. The level at which the interventions can best be initiated varies.

The interventions for this objective will be examined category by category in the following sections.

Preservice Teacher Education. This category of interventions is not very interactive, i.e., it can be considered quite independently of the other interventions. It is a long-term category, however, in that the impact will take considerable time to be noticed. Changes in preparation programs will not be instantaneous and the number of new teachers in any given school will not be large for some years after teacher preparation changes take place. While the state can initiate change through certification requirements, initiative at the institutional level clearly will be essential. The situation is analogous to that of initiating change in schools where research shows that there must be initiative at the building level.

Several of the interventions in this category are rated as medium-cost/medium-effectiveness. Some interventions involve greater science preparation for elementary teachers; research on the relationship between science background and teaching effectiveness indicate promise for this action. Lengthening of secondary teacher preparation also holds promise, especially with regard to professional education. Research shows a positive correlation between teaching effectiveness and both the amount of a teacher's science background and professional education preparation. Since science certification in Colorado requires nearly 60 semester hours of science (and the research gives some indication of a "plateauing" of the relationship between science background and teaching effectiveness at less than 60 hours) and the amount of preparation in professional education may be as little as a third of this amount, consideration should be given to increasing this professional preparation. In addition, there is a substantial collection of research studies showing that the teaching approaches of science teachers can be changed appreciably by well developed systems of training and practice. Thus the intervention which refers to more "hands-on" work has promise. Finally, the inclusion of courses emphasizing the applications of science knowledge for personal, societal or technological purposes has promise. It should be recognized as being more interactive than the other interventions in this category, however, in that realization of its full potential also will require changes in the science curriculum of the schools.

Inservice Education of Teachers. This category of interventions is highly interactive in that inservice education programs in general have not evidenced high impact, while inservice education also has been identified as a critical part of educational change endeavors. In essence, inservice education set up as an isolated activity independent of other activities probably will produce few results, while inservice education set up as part of a broader based implementation effort will be effective and in fact may be essential to the success of the overall endeavor. Inservice education is a relatively short-term intervention although the overall endeavor for implementing change of which it is a part probably has to continue over a period of some years if the innovation is to become established. Inservice education can be initiated at any one of many levels including the national level (as with the NSF-sponsored institutes of the past quarter century), the state level, the school district level, or even the school building level. As indicated previously, however, successful inservice education appears to be closely tied to building-level endeavors of a broader based nature. This fact does not mean successful inservice education could not be initiated at the state or national level, but there is not a lot of reason for optimism about its impact unless it is closely related to broader-based, building-level endeavors.

Improved Materials, Equipment, and Facilities. This intervention also should be considered from an interactive perspective since there is little to support the notion that substantial educational improvement will result directly from increased materials, equipment, and facilities. This conclusion may reflect the existence of a minimal base of such support in most schools. To whatever extent materials, equipment, or facilities are missing from a setting where they are needed for particular educational activities, they should receive attention. Essentially, they should be viewed as important in the educational process, but not the beginning point for significant educational improvement. Financial support for this intervention can come from the national, state, or local level, but the greatest impact from this intervention will occur when they are tied to some specific local need.

Industrial Assistance. These interventions can be divided into assistance in the form of money and materials and personnel assistance. The financial assistance available is not of a magnitude that can be expected to make major improvements in the quality of science education. The available personnel assistance likewise probably is not large, but it has the potential of adding a perspective to the professional expertise of the school district that is not typically present, particularly with respect to the applications of scientific knowledge and its relationship to technology. Thus, even though the overall impact may not be large, its uniqueness is such that it should not be ignored.

Another intervention having significant effectiveness, but possibly high cost, is summer employment for teachers. Its cost is highly dependent upon the situation into which teachers would be hired and their productivity in that setting. Because of its potential educational effectiveness, however, companies should make every effort to determine if summer employment of teachers can be initiated in ways which are not prohibitively expensive.

Objective #3--Appropriateness

Improving School Curricula. This objective, and the corresponding category of interventions, occupies a pivotal role in efforts to improve science education. It is the most value laden; there is not universal agreement as to what the appropriate curriculum should be. This category of interventions also is moderately interactive. Research on the NSF-funded curriculum projects of the last quarter century shows the development of new curricula materials, in and of itself, can be successful in terms of student learning. Other evidence indicates, however, that the impact of these curriculum projects could have been much greater if better mechanisms were employed for implementing them in the schools. Thus, to gain the full benefits of new curriculum development endeavors, substantial effort should be devoted to implementation of the resulting products on a long-term basis.

The experience of recent decades with respect to elementary school science programs highlights most prominently the need to coordinate curriculum development with implementation endeavors. Many science education leaders consider the NSF-funded elementary school science curriculum projects still to be current, appropriate, and valuable for elementary school use.[94] Their use in the schools, however, is not extensive. At the elementary school level, the evidence is strong that a high emphasis must be placed upon facilitating the use of curriculum materials, not just developing them. This need points to strong district- and building-level attention to implementation efforts in tandem with any production of new curriculum materials.

More than the other categories of interventions, this one probably should be pursued at a variety of levels, including both federal and local. There is a need for curriculum materials giving more emphasis to the applications of science. The federal role could include curriculum development projects, operating in a manner similar to the earlier NSF projects, along with the development of models and resource materials that could be used for further development at the state or local level. Development at the local level (or through regional consortia of school districts) is particularly attractive because of its potential for closely coupled implementation efforts in local school districts. Appropriate inservice education and local leadership, in combination with the curriculum development endeavors, greatly increase its potential.

Facilitation of Objectives #1, #2, and #3

The three categories of interventions presented here are intended to foster attainment of objectives #1, #2, and #3 as described previously. Obviously interactive, because of their orientation toward facilitating the effectiveness of other interventions, these categories must be considered in light of their potential impact when combined with other interventions. They can be initiated at various levels and be either short term or long term, although they tend toward long term.

Improving Local Leadership. As single interventions, none of those included in the category of improving local leadership received a rating above low in effectiveness. On the other hand, the research cited earlier on effective schools and implementing change indicates quite strongly that this local leadership is an essential ingredient that must be present if other interventions are to have the desired effect. This leadership probably will come from people in a variety of roles within the school district. Whether this leadership is provided by science supervisors, general curriculum directors, principals, or some combination of these persons, local school districts must give it high priority. When it is not present, federal and state agencies should channel resources toward providing the needed talent to "protect their investment" in other interventions they initiate.

Testing Programs. This intervention is interactive in the sense that it can be an important aid to changing the curriculum. Thus, it is closely tied to objective #3 concerning the appropriateness of the curriculum. To whatever extent new curricula are adopted with a somewhat different content than in the past, district testing programs can assist their acceptance by including test items consistent with the new curricula. It is an important step for local school districts (or states in those cases where they have state testing programs) to take in support of curricular change. It is a long-term endeavor in that the focus of testing programs rarely changes rapidly and changes which are made can be expected to persist for some time.

Public Education. This category of intervention is interactive with the others since public opinion and taxpayer decisions are the base upon which American education is built. Without public support for improvements in science education, little improvement is likely. As a category of interventions, however, it is not as prominent as most. To a large extent, the people who wish to improve science education in this country are not in a position to dramatically change public values. They must proceed mostly on the basis of the values society currently holds. There are important steps which can be taken to educate the public, of course, but they will more likely arise out of a broader context of concerns rather than from endeavors designed to directly improve science education.

Having dealt with the costs and effectiveness of many potential interventions and combinations of interventions, one is still left with the questions of which particular interventions should be initiated, by whom, and under what circumstances. Obviously the most cost-effective interventions are the ones of choice, but the interactions among the interventions, and the many variations in how a given one could be implemented, all point to the need for further judgments. Such value judgments are the core of this chapter. It is recognized at the outset that someone else may make a somewhat different set of choices based on the preceding cost-effectiveness analysis. This possibility is no reason, however, to back away from making the judgments. In view of the extensive investment in the analysis up to this point, it would be irresponsible not to do so.

Several basic considerations enter into these recommendations. First, it is assumed that the recommended interventions will be initiated in a coordinated manner. Research findings cited previously substantiate the importance of this approach. While in some cases a different intervention may be substituted for the one presented, it must be recognized that failure to provide an adequate substitute may negate the impact of some of the other recommended interventions.

Second, it is assumed that state or federal level interventions will be initiated in a manner that fully recognizes the importance of local initiative. While some interventions can be made independently at these higher levels, the majority of actions require major local involvement. The manner in which the federal and state interventions are made becomes crucial to their success. It is recognized that there is more than one level at which some interventions can be made, but in such cases, "ownership," commitment, and investment at the lower of the levels almost always is necessary if the intervention is to succeed.

A State Plan

The focus of the recommendations presented here is a state plan of action for improving science education. Imbedded within it are recommendations for local and federal action.

In view of the strong emphasis upon local initiative in the previous analysis, and the responsibility given local districts in many states for education, one may question why the focus is on the state. Certainly, it would be possible for a local school district, at least the larger ones, to make essentially all of the cost-effective interventions if it had the financial resources and will to do so.

A basic reason for this initiative is that states are constitutionally responsible for education. Appropriate leadership from the state can foster local initiative; it can encourage, assist, and stimulate without dictating local actions or limiting their choices. Local leaders still must grapple with all the issues involved; the outside resources can help them in doing so. A further reason is the quality of work that can be done in many arenas when there are people involved from a variety of settings. Even for larger school districts, outside stimulations generally are a positive influence. A vision for the future, goals, and alternative plans for action which reflect indepth knowledge of science, technology, and even educational practice simply are not present to the fullest extent in all school districts. A final reason is the economy of scale in taking some actions, such as development of curriculum materials, at a higher level. The per pupil cost can be strikingly different.

But why should this leadership come from the state rather than the federal level? The main reason is the current tide of events. Across the country states are assuming growing responsibility for education. As the movement increases, the federal initiatives that do develop are likely to assume a growing state involvement. Another reason for state leadership is its greater proximity to the local level, an important consideration in view of the importance of local initiative. A final reason for not depending on federal action is the apparent low probability that actions will be taken at that level in the immediate future having the systemic orientation highlighted by the analysis presented above. Strong leadership at the state level appears to have the greatest potential for significant improvement in science education at the current time.

Key Elements of the Plan

While containing a collection of specific recommended actions, the proposed endeavor is characterized by a systemic orientation--simultaneous attention to the full range of objectives (quantity, quality, and appropriateness) and means of attaining them together. The following specific interventions should be viewed in that light, not as a list from which to pick and choose.

This state initiative must be a dynamic ongoing program in which leadership is exercised in the form of clear-cut goals, ongoing assessment of progress, communication and cooperative planning with local leaders and provision of the resources and assistance needed by local districts in meeting the desired objectives. The desired approach is analogous to that described in the research literature for effective principals. All the details cannot be spelled out ahead of time. The plans must be open enough and the leadership effective enough that actions can be modified over time. A given state, of course, will need to carefully develop its own strategy to involve the appropriate people and establish reasonable timelines and budgets. This endeavor will require a leader, such as a state science supervisor, whose time is allocated to the task and who has excellent leadership skills. Within this context the following interventions are proposed as the basis of a state program.

1. Provide funding and professional assistance to local school districts for developing local leadership and science education improvement programs leading to attainment of the quantity, quality and appropriateness objectives.
2. Fund the improvement of teacher education programs including (a) the addition of more "hands-on" activities in professional education and (b) more instruction in the sciences which deals with its applications.
3. Provide training for local school district personnel on curriculum development and implementation.
4. Fund the establishment of consortia of school systems, universities and other groups within the state to engage in curriculum development.

5. Develop new standards for the adoption of science textbooks that give greater emphasis to the applications of science. (not applicable to Colorado)
6. Provide information for local school board members on needed improvements in science education.
7. Provide conferences for local school district testing personnel to assist them in developing tests that will give more emphasis to the applications of science and be consistent with local science curricula.
8. Fund the development of item banks, with test items on the applications of science knowledge, from which local districts can draw items.
9. Provide awareness conferences and publications for local accountability committee members which will inform them of the needs of science education and describe means for improving it.
10. Establish leadership for the above interventions which will enable them to proceed in a coordinated manner with appropriate modifications as indicated by evaluation and communication with local educational personnel.

The basic purpose of the above plan is to improve science education in local school districts. The success of this state endeavor will be measured by the extent to which local interventions are initiated to attain greater quantity, quality, and appropriateness of science instruction. The intent is to encourage the implementation of coordinated local programs composed of the following interventions.

Objective #1: Quantity

1. Increase high school graduation requirements to include more science than currently is required.
2. Increase the homework required in secondary school science classes.
3. Initiate actions to help teachers more fully utilize the instructional time available in their classes, i.e., increase "engaged time."

Objective #2: Quality

4. Develop local programs of teacher recognition, professional development, and improved professional environment.
5. Improve teacher recruitment and selection processes.
6. Provide better supervision and evaluation of science teachers.
7. Introduce improved instructional practices such as mastery learning or one or more other practices documented by research to be successful.
8. Conduct inservice education in support of the various interventions as needed.
9. Provide improved materials, equipment and facilities as needed in support of the other interventions.

Objective #3: Appropriateness

10. Initiate local curriculum development endeavors in elementary and secondary school science, either in individual local school districts when they are large enough, or in consortia of districts.

Facilitation

11. Initiate improved program evaluation in local school districts with particular attention to the appropriateness of goals, the degree to which they are attained and means of improving the science programs.
12. Initiate additional supervisory assistance for science teachers which is focused directly on the improvement of instruction.
13. Initiate careful selection procedures and professional development for principals.

The state endeavor also is related to possible federal interventions. Existing federal programs should be viewed as possible sources of support for activities included within the state plan or the endeavors of local school districts. In addition, state personnel should seek to influence emerging federal programs to focus upon the interventions shown by cost-effectiveness analysis to be valuable for the systemic effort being fostered by the state plan. Specifically, the following federal interventions should be encouraged.

1. Provide inservice "institute" classes for science teachers which (a) update teachers' knowledge in science, (b) assist in the implementation of new science curriculum programs in local school districts, and (c) have an integral relationship to local school district science education improvement endeavors.
2. Fund science curriculum development projects with particular attention to those emphasizing the applications of science and focused upon the general student.
3. Fund the establishment within states of consortia of school systems, universities and other groups to engage in curriculum development.
4. Fund research work which will increase the knowledge base needed for (a) curriculum development of the type described in #2 above, (b) careful analysis of the problems of science education, and (c) identifying the actions needed to improve it.
5. Provide an awareness conference for test publishers on the need for new science tests giving greater attention to the applications of science.
6. Provide funding to sustain state programs as described above.

In making the choices required for developing the above recommendation, cost has been considered, especially in terms of the cost to the taxpayers. It has been calculated in terms of the impact on the average total annual expenditure per student. These data differ from the information provided earlier in that the previous information was expressed in terms of the average annual cost per student benefiting from the intervention; the costs presented below have been "spread across" all students in a district, including those who do not benefit from the particular intervention. Thus, for example, an intervention costing $13.00 per student and affecting all students in 9th grade, but only this grade, would, when "spread across" all thirteen grades (K-12), result in an increase of approximately $1.00 per student in the average annual district per pupil cost of education. Similarly, a federal expenditure of $41,000,000 would represent an increase of approximately $1.00 per student in the average annual cost of educating all U.S. students since there are approximately 41,000,000 students in the U.S. Some interventions recommended here would be valuable for students other than science students; extending the proposed action to all students, of course, would increase the average annual per pupil cost of education.

The interventions described above are estimated to increase the average annual per pupil cost of education by $3.37, $0.81, and $1.47, respectively, at the local, state, and federal level. The total is $5.65 per pupil per year. The details of these cost calculations are provided in Table A.3. in the Appendix of this report.

The above total per pupil cost would be effected substantially if one or more promising but relatively costly interventions were included, such as extended year contracts for all science teachers to engage in curriculum development work or substantially higher salaries for science teachers to make them competitive with alternative employment. Such interventions are not being discouraged here. It is simply that as a matter of first priority, the above plan is presented as a cost-effective way to initiate a promising program of improvement in science education.

Serious attention should be given to additional support which complements the above program. The program could be supported at a higher level. tended year contracts may be quite effective if initiated within the context this program. Higher teacher salaries may be important as a <u>long-term</u> plement to the program. The specific actions listed as a program are a arting point. This report says more about where to start than how far to o.

<u>A Final Word About a Systemic Approach</u>

The importance of viewing the above recommendations as a totality rather than a listing from which to choose a few interventions is difficult to overemphasize. This perspective is supported by the research on effective schools and implementing educational change reviewed earlier. It also is supported by the analysis presented earlier. Requiring more science for high school graduation, for example, without concomitant attention to the appropriateness of the curriculum poses potentially serious problems. This requirement would affect mostly the non-college-bound student, yet the current senior high school curriculum basically is designed for the college-bound student. Curricular change is needed along with any increase in requirements.

The question of what goals should be pursued in science instruction permeates the entire analysis of this report. Everyone involved with science instruction in the schools must grapple with this issue. The research on effective schools highlights the importance of a goal-orientation; yet the results of the survey of Colorado educational leaders described in a subsequent portion of this report (Part III) show there are essentially two different orientations to this question. The majority position is that the applications of science need significant attention in the curriculum, but a significant minority are not persuaded of this importance. The issue must be debated and whatever the outcome of the debate, a course must be struck based on clearly understood goals, carefully developed plans of action, effective communication among all parties involved, and a resolve to put the plans into effect. In this manner, substantial improvement in science education can be pursued with optimism.

In essence, the potential impact of the program of interventions described above is significantly greater than the sum of its parts. The costs described above are rather minimal given any serious commitment to improving science education. If costs absolutely must be reduced even further, however, the total should be scaled down somewhat rather than eliminating some parts. It is imperative that a systemic approach be maintained.

PART II. MODIFICATIONS OF THE ANALYSIS AS IT PERTAINS TO MATHEMATICS EDUCATION

Although both science and mathematics are of concern for this analysis of the most cost-effective means of improving education, the first and by far the largest section of this report deals only with science. While it would have been possible to report the results of the analysis in a report which combined the analysis of the two teaching fields, the two fields have been separated because (1) mathematics and science are fundamentally different in character and (2) there are two different bodies of research literature for the two fields.

In this part of the report, the previously presented analysis for science education will be reviewed with specific attention to the ways in which the analysis must differ for mathematics. This review will be done in terms of (1) the single interventions, (2) the combinations of interventions, and (3) the recommendations. In most cases the analysis for mathematics will show results similar to science; in a few cases the results will be different or simply unknown.

Single Interventions for Improving Mathematics Education

The single interventions for improving education will be examined individually within each of the eleven categories in order to identify differences between mathematics and science.

Interventions Primarily Related to Objective #1: Quantity

The interventions related to this objective all are in the category of increasing student requirements. None of these interventions is subject specific; in other words, the analysis presented for science pertains to mathematics as well. The per student costs for introducing these interventions are the same in mathematics classes as in science classes. The impact on total school budgets, and thus on the average annual pupil expenditure in a district, state, or the nation, of course, would increase if the intervention were introduced for both mathematics and science. This impact on average annual pupil expenditures will be addressed with respect to recommendations presented in a later section.

Interventions Primarily Related to Objective #2: Quality

1. Preservice Preparation of Teachers

In most regards, the situation for mathematics is similar to science. Differences arise with respect to the nature of the intervention and the context in which it is implemented in a few cases. The cost of initiating greater mathematics requirements in the preparation of elementary teachers is essentially the same as for science, but its effectiveness potentially is different. In contrast to science, mathematics generally is given major attention in the elementary school curriculum and actually is allotted as much time by teachers as the schedule would indicate. Thus, there is little reason to think that a better mathematics background would result in teachers teaching it more. In general, a better background in the given subject field, be it science, mathematics or some other field, is desirable, but there may be less evidence of its importance in this case than in the case of science. Similarly, the analogue of more college courses emphasizing the applications of science would be courses emphasizing the applications of mathematics. This intervention also is related to objective #3 concerning appropriateness. It is not clear that there is need for college courses emphasizing the applications of mathematics, but the more general curricular issue will be addressed later with respect to objective #3.

2. Enhancing Teaching as a Career

The analysis presented for interventions designed to enhance teaching as a career holds for mathematics teachers as well as science teachers.

3. Improving Instructional Practices

The analysis presented for improving instructional practices also holds for mathematics as well as science, but in either case there is less specificity in this analysis than the previous one concerning enhancing teaching as a career. The second intervention in this category, mastery learning, was in essence a place holder for a large collection of potentially improved instructional practices. Because of the difference in the nature of the subjects, differences in the efficacy of various instructional practices could be expected as well. A thorough analysis of the many potentially improved instructional practices which could be considered in either science or mathematics is beyond the scope of this report. The substantially improved learning resulting from some interventions of this type, however, such as the previously cited results of mastery learning in science, must not be forgotten. Interventions of this type have significant promise.

4. Inservice Education of Teachers

There is little in the analysis of interventions concerning inservice education that would be expected to be different for mathematics than for science. While the evidence cited for the indifferent record of summer institutes was from the area of science, there is little reason to expect the evidence in the area of mathematics to present a different picture. The intervention regarding the applications of knowledge in the curriculum raises the same issues about the goals of education mentioned earlier and will be addressed more fully below with respect to objective #3. As in the case of science, the systemic nature of the situation must constantly be borne in mind; the intervention describing inservice education coordinated with local development endeavors is especially attractive and will be considered further when combinations of interventions are addressed.

5. Improving Mathematics Materials, Equipment and Facilities

As a single intervention, the analysis is similar for both science and mathematics with the exception that the costs of non-text materials is substantially less in mathematics than in science. Even more so than in science, the addition of materials apparently is not the most critical factor in improving instruction.

6. Industrial Assistance

With the exception of donations of equipment, the analysis of this category of interventions is essentially the same for mathematics as for science. Even in the case of equipment, the situation is not that different in that the donations of equipment available often are not that usable or appropriate for instructional use.

Interventions to Attain Objective #3: Appropriateness

This objective and the related category of interventions, improving the curriculum, differ more than the others from science to mathematics. Appropriate goals of instruction are highly related to the particular subject field. In exploring the question of appropriateness with respect to mathematics, two findings from research are particularly significant. First, as in the case of science, the research establishes quite clearly that the mathematics curriculum in the schools is defined by the textbooks in use. Teachers teach whatever is in the textbooks. Secondly, mathematics, as in the case of science, is viewed as important for preparing for the next level of schooling, not because it has become a direct value in and of itself. At this point the analysis _may_ part company, since what makes a subject valuable to a person may vary considerably from one field to another. In science, for example, the case was made that personal applications of the knowledge and its application to various societal issues should have more of a bearing on what science is taught in the schools. In mathematics the issue may be similar in one respect; it may be valuable to teach students more directly the use of mathematical knowledge in personal applications. In another respect, it may be quite different, in that mathematics may not be as overtly a part of the ebate on many societal issues in the same way that science is. The extensive cience knowledge required for serious analysis of many of the issues faced by ur society probably places a demand on the science curriculum that is not laced directly on the mathematics curriculum. So, the debate over what athematical knowledge is of most worth in the curriculum may take a onsiderably different form than in science, but the debate, nonetheless, is ritically important. It must take place and the outcome of the debate should e allowed to shape the curriculum even if it means the curriculum is ubstantially altered.

As noted previously with respect to science, this category includes two eneral types of interventions. The first directly addresses particular types f changes in the curriculum; they are based upon value judgments as to what s appropriate. The second type of intervention focuses on a particular echanism for bringing about desired change. A particular shift in the focus f the curriculum is assumed and the question becomes one of assessing the alue of particular mechanisms for producing this change.

The first three interventions in this category deal with particular changes in the content of the curriculum. The costs are basically the same as for science. The effectiveness of the interventions is not as predictable. In fact, these interventions, as described with respect to science, may be inappropriate for mathematics. Thus it may be necessary to suggest totally different interventions which are viable candidates for consideration as a result of thorough debate over the question of what mathematical knowledge is of most worth for various kinds of students. This debate is beyond the scope of this project and will not be pursued here. Suffice it to say that the debate is critically important and should be pursued vigorously in the interest of providing a sense of direction for mathematics education.

The other interventions in this category pertain to mechanisms for bringing about the desired curricular change. The analysis is essentially the same as for science given that the particular curricular change has been identified. Thus, if the goal questions can be resolved, one can proceed to evaluate how best to pursue the desired change. As in the case of science, the systemic nature of the situation is such that the interactions among the interventions must be considered. This facet of the analysis will be considered further in the context of other interventions and with full consideration for potential interactions.

Facilitating Interventions

The facilitating interventions are not very subject specific; the analysis presented for science can be used essentially as is for mathematics also. Almost all of the facilitating interventions are highly interactive; they can be addressed most readily in the following section on combinations of interventions.

Combinations of Interventions for Improving Mathematics Education

The analysis of combinations of interventions for science was largely based upon a synthesis of the research on effective schools and means of introducing educational change. This same analysis applies to mathematics as well. The major implications of that analysis are as follows. First, interventions must be considered in combination, not in isolation. Second, the combination of interventions cannot omit a particular one crucial for making the combination effective. Third, whatever combination of interventions is selected, it must be based upon a multi-level perspective, including classroom, school, district, state, and national levels.

As in the case of the single interventions, the major difference between the analyses for science and for mathematics grows out of differences in the nature of the curriculum content and the instructional goals. Thus, any intervention related directly or indirectly to objective #3, appropriateness, must be considered carefully for differences resulting from its subject-specific nature.

Recommendations

As in the case of science, recommendations are based on the assumption that all actions will be initiated in a coordinated manner and not considered as single interventions. A state plan similar to the one proposed in science also is proposed for mathematics. It is similar in scope, has the same general interventions (except as modified for the appropriateness objective as indicated above), and costs essentially the same.

PART III. A DELPHI STUDY OF LEADER'S VIEWS OF INTERVENTIONS FOR IMPROVING SCIENCE AND MATHEMATICS EDUCATION IN COLORADO

As a supplement to the cost-effectiveness analysis contained in this report, a series of questionnaires was sent to educational leaders in Colorado to determine their opinions about the current status of science and mathematics education in the state and actions that should be taken to bring about positive change. Sometimes referred to as a Delphi study, the series of questionnaires was designed as an iterative process in which information from previous questionnaires is summarized and reported back to the respondents for their reaction. It provides an opportunity to learn the opinions of others and potentially be influenced by this information in forming their conclusions. The process has the potential of achieving some consensus, somewhat as in a group discussion, but without the possibility of forceful individuals dominating the process. In addition to the possibility of forming a consensus, of course, it has the potential of identifying areas where there are differences of opinion with no consensus possible.

This endeavor was designed to gather people's judgments with respect to four main topics.

1. What are the major problems with science and mathematics education, and how serious are they?
2. What goals should be pursued in science and mathematics education in elementary and secondary schools?
3. What actions have the potential of improving science and mathematics education?
4. What are the perceived costs and effectiveness associated with the various actions under consideration?

The opinions of eight categories of people were sought as follows.

1. Superintendents and principals
2. School board members
3. Curriculum directors and supervisors
4. Teachers
5. Vocational educators (administrators)
6. Higher education personnel (administrators and science and mathematics professors)
7. Colorado Department of Education personnel
8. Elected officials (Legislators who are members of the House and Senate Education Committees and State Board of Education members)

This endeavor sought the opinions of <u>leaders</u> in each of these categories, not a cross section of individuals. Rather than a random sample, nominations of leaders in each category were obtained. For example, the superintendents and principals contacted were nominated by officers in various professsional associations and by other individuals having an informed opinion about occupants of these positions throughout the state. In addition to identifying people in each category who are regarded as leaders and whose opinion is respected by their peers, efforts were made to include people from the various geographic regions of the state and from various types of settings, such as urban and rural.

After the list of potential participants was developed, a letter was sent to each person requesting his or her participation in the study. Of the 225 people contacted, 173 agreed to participate. Each of these persons then was sent the first of a series of three questionnaires.

The approach followed allowed for followup of non-respondents to the questionnaire while also preserving their anonymity. A postcard was provided with each questionnaire which the respondent was asked to return separately from the questionnaire indicating that it also had been mailed. Only the postcard contained the name of the person. Persons from whom no postcard was received were sent a follow-up questionnaire in an effort to obtain as many respondents as possible. The questionnaires were color coded to identify the particular group (i.e., superintendent or principal, school board member, etc., as described above), but no names were included on the questionnaires.

Questionnaire #1

The first questionnaire contained only open-ended questions, ten in number, which the respondent was expected to answer by writing out phrases or sentences. The questions were fairly broad and solicited the opinions of the respondents with regard to the issues identified above as the main focus of the study. No marked differences were obvious among the respondents in terms of the group to which they belonged (i.e., school board member, teacher, elected official, etc.). The responses are summarized below.

When asked, "How well are we doing in pre-college science and mathematics education? The headlines say there is a crisis; what do you think?" nearly two-thirds of the respondents said the situation was a problem but were reluctant to call it a crisis. The remainder of the respondents were divided between calling it a crisis or no problem.

When asked to identify the most pressing issue facing science and mathematics education today, the responses were many and included a wide variety of answers. Within this wide variety of responses, one stood out from the others because of the frequency with which it was mentioned. Although expressed in different ways, this most pressing issue pertained to the quality of teaching.

When asked how good a job is being done in science and mathematics education as compared to other areas of study in the schools, about 60 percent thought it was the same while approximately 30 percent indicated we are doing worse in science and mathematics and 10 percent think we are doing better. Although the difference is very slight, the responses indicate comparatively better performance in mathematics than in science.

When asked to identify what groups of students in the schools are being served most poorly now (considering such variables as grade level, ability, ethnicity, sex, and post-secondary educational or vocational plans), a wide variety of variables were identified. Gifted students, average students, and less gifted students were each mentioned about as frequently as the others. In terms of grade level, elementary students were mentioned about twice as frequently as middle school students who in turn were mentioned twice as often as high school students. In general, the problem apparently is perceived to be greater at the lower levels than at the higher levels. Minority students and female students were cited by some respondents as groups poorly served.

Some respondents identified the "general" student as the one most poorly served while a substantially lesser number referred to the "academic" student as the group most poorly served.

When asked to describe what the goals of science and mathematics education should be, a wide variety of responses was received, but a pattern emerged. Respondents saw distinctions among groups of students, most often noting a distinction between two clearly identified groups of students. One group, sometimes called "academic," consisted of those likely to go on to colleges, often to major in science, mathematics, or engineering. There appeared to be a general consensus that the primary responsibility here is providing a challenging college-preparatory course of studies in science and mathematics to enable these students to compete and succeed in college. Another group consists of those students unlikely to pursue such rigorous collegiate coursework, but who will constitute the majority of our future work force and citizenry. This second group was sometimes designated as the "general" student. Many respondents believed the primary responsibility towards this group was teaching them those aspects of science and mathematics most likely useful in their everyday personal lives, and also to prepare them to be sufficiently literate about science and technology for their role as voting citizens.

When asked what would most improve science and mathematics education, a large number of different responses was received. Within this lengthy listing, however, the most frequently mentioned responses pertained in some way to teachers. When the responses were placed in categories, the most frequently mentioned were higher quality teaching, higher salaries for teachers, and improved teacher preparation.

The respondents to this questionnaire also were asked if the school district by which they were employed (or if not an employee, the district in which they resided) was likely to spend more money on science and mathematics education to bring about some improvement. The majority of respondents had an opinion on this matter, and of those who did slightly more than half said "no"; approximately one-sixth said "probably," and the other one-third said "definitely" their district would spend more money.

While these general responses were helpful, there were two areas needing further attention which were pursued in the subsequent questionnaires, namely further information about the goals which science and mathematics education should pursue and the particular actions or interventions which are most likely to bring about improvement in the current situation.

Questionnaire #2

Based substantially on the response to the first questionnaire, a second was developed which was more structured and focused upon three major areas. It began with a description of the distinction noted above between "academic" and "general" students. The respondents then were asked the amount of change they felt was needed in school programs to meet the needs of these two groups. The structured question made distinctions between science and mathematics and between elementary, junior high/middle school, and senior high school. The results of this query are summarized in Table 4. It is clear from these data that the vast majority of respondents felt that change was necessary, but moderate change was more attractive than major change.

Table 4

The Amount of Change Needed in the Science and Mathematics Education of Students As Rated by Colorado Leaders

Categories of Students	Superintendents & Principals (18)	School Board Members (18)	Curriculum Directors & Supervisors (14)	Teachers (25)	Vocational Educators (6)	Higher Education Personnel (19)	CDE Staff (6)	Elected Officials (4)	Total (110)
Academic Students									
Elementary Sci.	1.22	1.22	0.93	1.67	1.00	1.17	1.60	1.25	1.27
Elementary Math.	1.11	1.12	0.79	1.39	1.00	1.22	1.40	1.25	1.17
Jr. High Sci.	1.33	1.45	1.00	1.59	1.17	1.27	1.50	1.50	1.36
Jr. High Math.	1.11	1.50	1.00	1.48	1.17	1.32	1.50	1.50	1.32
Sr. High Sci.	1.06	1.39	0.85	1.36	1.00	1.36	1.33	1.75	1.24
Sr. High Math.	0.94	1.39	0.64	1.32	0.83	1.53	1.33	1.75	1.21
General Students									
Elementary Sci.	0.89	1.11	0.79	1.29	1.17	0.95	1.20	1.00	1.05
Elementary Math.	0.72	1.00	0.72	1.08	1.17	0.95	1.20	1.00	0.95
Jr. High Sci.	0.94	1.28	1.21	1.25	1.50	1.10	1.33	1.25	1.19
Jr. High Math.	0.83	1.40	1.07	1.40	1.50	1.27	1.33	1.25	1.24
Sr. High Sci.	1.00	1.48	1.36	1.17	1.17	1.22	1.17	1.50	1.24
Sr. High Math.	1.00	1.39	1.43	1.36	1.00	1.27	1.33	1.75	1.29

Major Change = 2
Moderate Change = 1
No Change = 0

The second section of the questionnaire dealt with the importance of various goals one might have for science and mathematics education. The various goals included understanding of fundamental principles of science and mathematics, preparing students to deal with science-related societal issues, preparing students to apply science and mathematics knowledge in their everyday lives, and giving students a better understanding of science- and mathematics-related careers. The responses to this structured question are contained in Table 5 below. The most striking conclusion that comes from this table is that, although there are some variations, seemingly everything is important.

The third part of the questionnaire contained a detailed listing of many possible actions or interventions for improving science and mathematics education. These interventions were derived from the results of the first questionnaire as well as other sources, and included most of the interventions addressed elsewhere in this report. Respondents were given an opportunity to rate both the effectiveness and the feasibility of each of the specific interventions. The summary of these ratings in Figure 6 below includes the effectiveness and feasibility ratings of the total group of respondents for each of the eleven categories. There is variation in the ratings for these groups of interventions, more so for the effectiveness ratings, however, than in the feasibility ratings. The highest effectiveness ratings were given to those intervention categories relating to teachers; they were rated approximately midway between effective and highly effective. The lowest rated interventions, testing programs and improved leadership, were rated approximately midway between somewhat effective and effective.

Questionnaire #3

The third questionnaire contained two parts, both built upon information obtained in the previous questionnaire. The first of these two sections dealt with goals for science education; mathematics was not included in this part of the questionnaire.

The goals section included information derived from recent research as well as from the previous questionnaire. It was noted above that respondents to questionnaire #2 generally thought all of the various goals were important. The great majority were rated in the mid-range between important and very important, with the few exceptions simply being rated important. None were considered slightly important or unimportant. The questionnaire then went on to raise some questions growing out of these judgments and some data about the current science curriculum in the schools. It was noted that the current junior and senior high school curriculum (whether for "academic" or "general" students) contains little on societal issues, personal applications, or career preparation. Several studies using different methods consistently show the same results. The average amount of actual instruction time in science classes devoted to all of these matters combined is in the neighborhood of 5 percent. This instructional time is proportional to the attention given these topics in the current textbooks. There is an apparent contradiction between the goals espoused by the respondents to this questionnaire and school practice. The questionnaire then went on to raise the following question with respect to the "academic" students to which the respondents were expected to respond in an open-ended fashion with their comments.

Table 5

Average Rating of Various Goals for Science and Mathematics Education by Several Categories of Colorado Leaders

Goals	Superintendents & Principals (18)	School Board Members (18)	Curriculum Directors & Supervisors (14)	Teachers (25)	Vocational Educators (5)	Higher Education Personnel (19)	CDE Staff (6)	Elected Officials (4)	Total (109)
damental Princi-s of Science & hematics									
cademic Students	2.72	2.75	2.82	2.80	2.40	2.79	2.33	3.0	2.74
eneral Students	2.56	2.38	2.36	2.48	2.00	2.42	2.17	2.25	2.40
ence Societal ues									
cademic Students	2.50	2.38	2.36	2.76	2.20	2.26	2.33	1.25	2.41
eneral Students	2.28	2.29	2.36	2.64	2.20	2.16	2.33	1.50	2.32
sonal Applications Science									
cademic Students	2.5	2.06	2.15	2.44	2.00	1.79	2.00	2.0	2.18
eneral Students	2.39	2.28	2.36	2.56	2.40	1.63	2.33	2.25	2.27
sonal Applications Mathematics									
cademic Students	2.50	1.94	2.53	2.28	2.20	2.05	1.83	2.75	2.24
eneral Students	2.72	2.61	2.84	2.56	2.60	2.26	2.33	2.75	2.58
eers--Science & hematics Related									
cademic Students	2.22	2.17	2.53	2.28	2.60	2.0	2.00	2.50	2.24
eneral Students	1.72	2.00	2.15	2.00	2.40	1.58	1.83	2.25	1.92

= Very Important = 3 I = Important = 2 SI = Slightly Important = 1 U = Unimportant = 0

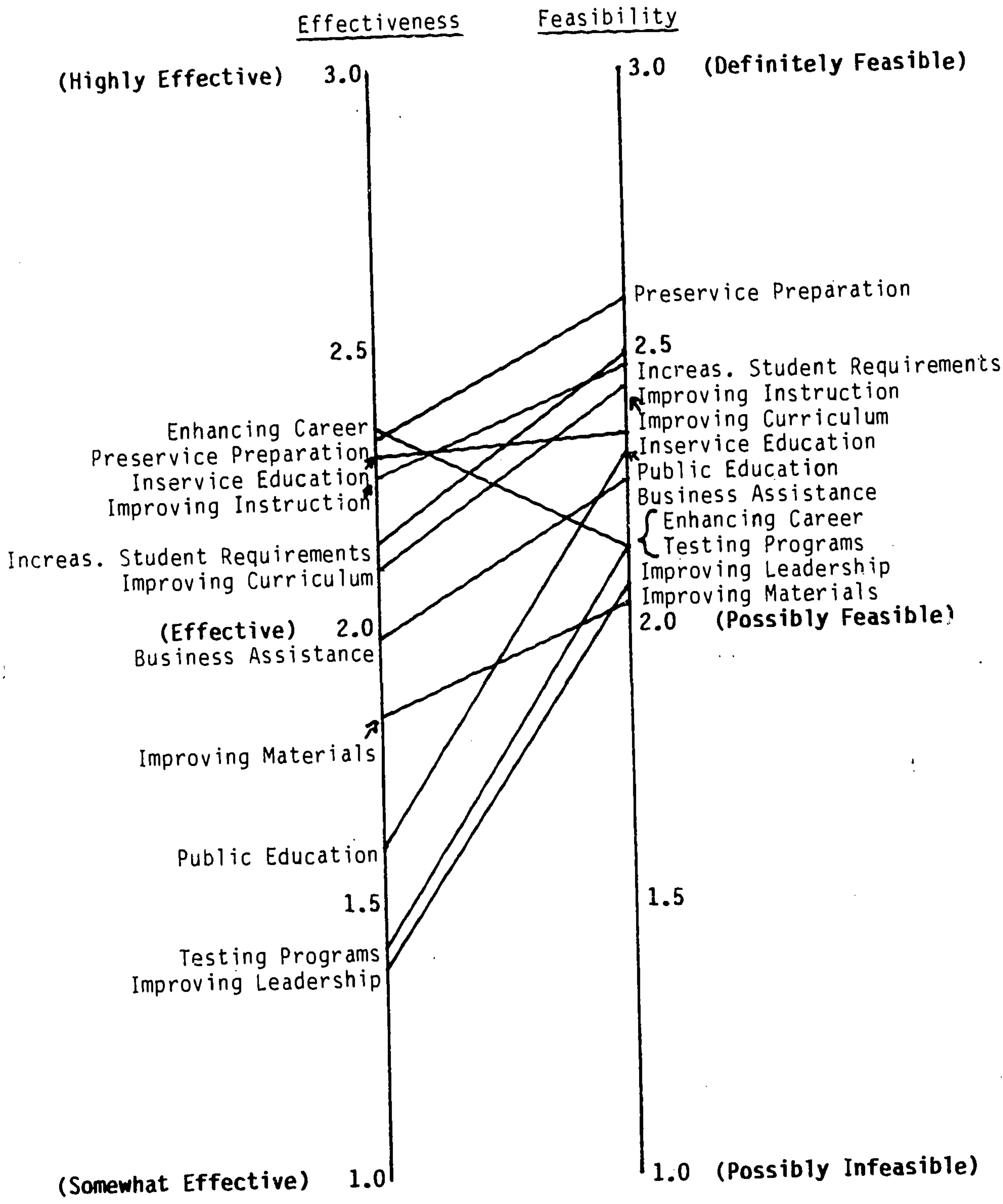

Figure 6. Ratings of Effectiveness and Feasibility of Intervention Clusters by Colorado Leaders

"Would you advocate modifying the curriculum to take care of this discrepancy? If so, in what way, to what extent, and why?"

It then was noted that enrollment figures show "general" students typically take the minimum amount of science required for graduation. Current science programs are oriented to the "academic" students. This conclusion is substantiated by analyses of the curriculum content and by studies of the rationale teachers give for what they teach. If the "general" student is required to take more science from the current school offerings, it will be science designed for the "academic" student. The question then posed was

"Is this problem one that requires change in the science curriculum? If so, in what way, to what extent, and why?"

The responses to these two questions were categorized and are summarized in Table 6. In general it can be said that the respondents see a need for change in the curriculum for "academic" students by a margin of approximately three to one. A need for change in the orientation of the curriculum for "general" students is also favored, but the margin is less, not quite two to one.

Even more insight is gained from the reasons contained in the comments made in response to the open-ended questions. There was considerable uniformity in the rationale given by the respondents in each of the groups. Their rationale provides important clues as to the nature of the debate over science education goals and clearly indicates there is not a definitive consensus as to what the orientation of the curriculum should be. The respondents who felt that the curriculum for "academic" students should have more than the current 5 percent of time devoted to personal applications, societal issues, and career preparation generally made arguments for their importance in the curriculum. They referred to the need for more personal applications and attention to societal issues and were persuaded the curriculum needed to be "less theoretical." The amount of change suggested is also of interest. Many respondents commented on the need to change and at the same time cautioned that the change should not be too much. Science instruction needed to be more related to life, but they were looking for a modification to the existing curriculum, not a wholesale replacement with a totally different approach.

The minority of respondents who felt the curriculum should not change were convinced such changes would "dilute" the curriculum and that subject matter needed to be emphasized. There were comments about the need to "clean out" students and to have "discipline" as a goal for the curriculum. Some felt that science-related societal issues should be addressed in social studies rather than in science classes.

The reasons given for the answers to the question about the need for change in the curriculum for "general" students reflected values similar to those expressed above. The majority who felt a change was needed in the curriculum argued that it needs to be more practical, less theoretical, and have more of an experiential base. They were persuaded of the importance of preparing students for voting and citizenship. The curriculum should emphasize "everyday science" with attention to "hands-on" experience and exploration of scientific phenomena.

Table 6

Opinions of Colorado Leaders as to Whether or Not the Science Curriculum Should be Modified to Give more Attention to Personal Needs, Societal Issues, and Career Preparation

	Academic Students				General Students			
	Yes	No	No Response	Total	Yes	No	No Response	Total
Supts. & Principals	11	2	2	15	9	4	2	15
School Board Members	13	5	2	20	8	8	4	20
Curriculum Directors & Supervisors	9	4	2	15	9	2	4	15
Teachers	9	3	4	16	7	6	3	16
Vocational Educators	3	0	0	3	3	0	0	3
Higher Education Personnel	11	4	1	16	9	5	2	16
CDE Staff	4	1	0	5	4	1	0	5
Elected Officials	3	1	1	5	2	2	1	5
Total	63	20	13	95	51	28	12	95

Those persons who saw no need for a change were persuaded that everyone needs the "academics" and the "fundamentals." Along with these predominant opinions were a few comments about the possibility of the general student deciding to go to college in the future, and comments indicating the schools already have enough general courses.

A second part to the third questionnaire provided another opportunity to rate the effectiveness and feasibility of various interventions. Only the more highly rated interventions from the previous questionnaire were included along with a few others which had not been included in the first questionnaire. Those interventions from the second questionnaire included the seven highest rated of the eleven previously used categories. When presented in this third questionnaire, the various single interventions within each category were listed in the order of their rating on questionnaire #2. With this information about the rating of the interventions by other respondents now at hand, the recipients of the questionnaire had an opportunity to rate them again. The results of these ratings are summarized in Table 7.

Implications of the Findings

Two aspects of the findings of this Delphi study have particular implications in the search for means of improving science and mathematics education: (a) the educational goals held by educational leaders and (b) the opinions of various means of improving education.

There is not a clear consensus on the desired goals of science and mathematics education, a situation which may impair progress toward improving this education. There appears to be a dichotomy between those who favor significant attention in the curriculum to the applications of knowledge and those who believe it should focus almost exclusively on fundamental knowledge, independent of applications. This difference in values seems to pertain to both "academic" and "general" students.

In addition to these differences in values, consensus on the question of goals is restricted by false assumptions about educational practice in the schools and the nature of learning. For example, it is well documented that only about 5 percent of the science curriculum in schools is devoted to science-related personal needs, societal issues, or career preparation combined, but most educational leaders assume the figure to be higher. It would have been interesting to extend the Delphi study to a fourth role and include additional information which is not widely known about the very low correlation between the amount of science taken in high school and success in college science courses. Such information has a bearing on the debate over goals.

It is important that the goals of science education be debated. Some degree of consensus is needed if positive action is to be taken to improve science and mathematics education. Such agreement is an important prerequisite for good planning and for effectively implementing these plans for positive educational change.

The second implication of these findings is that mobilizing effective action for change may be impaired by differences between the opinions of educational leaders as to effective actions for change and those identified by cost-effectiveness analysis. Among educational leaders collectively, it does not appear that many particular interventions stand out as the ones of choice. There is a lot of variation among individuals, but even within various

Table 7

Ratings by Colorado Educational Leaders of the Effectiveness of Various Interventions for Improving Science and Mathematics Education

Interventions	Superintendents & Principals (13)	School Board Members (18)	Curriculum Directors & Supervisors (14)	Teachers (12)	Vocational Educators (3)	Higher Education Personnel (16)	CDE Staff (5)	Elected Officials (5)	Total (86)
1. Preservice Preparation									
a. New standards	2.31	2.33	2.21	2.42	2.67	2.44	1.80	2.60	2.34
b. Greater sci. & math. for elem. teacher	2.47	2.61	2.29	2.42	2.00	2.32	2.40	2.60	2.42
c. More courses on applications	2.39	2.22	2.36	2.92	3.00	2.06	2.20	1.80	2.34
d. Specialized prep. for grades 4-6	2.01	2.56	1.72	2.50	2.67	1.94	1.60	2.20	2.14
e. More "hands-on"	2.62	2.34	2.22	2.50	3.00	1.94	1.80	1.40	2.25
f. Loans or scholarships	2.55	2.05	1.86	1.83	1.65	1.81	2.20	1.60	1.99
g. Stronger enforcement of full credentials	2.01	2.22	1.79	2.17	2.34	2.25	1.80	1.40	2.05
h. Student teachers with outstanding coop. teachers	2.38	2.39	2.57	2.33	2.67	2.19	2.20	1.40	2.31

Interventions	Superintendents & Principals (13)	School Board Members (18)	Curriculum Directors & Supervisors (14)	Teachers (12)	Vocational Educators (3)	Higher Education Personnel (16)	CDE Staff (5)	Elected Officials (5)	Total (86)
2. Inservice Educ.									
a. Summer institutes	2.07	2.17	2.22	2.42	2.33	2.31	2.00	2.25	2.23
b. Inservice courses on applications	2.15	2.33	2.07	2.50	2.33	2.13	2.20	2.20	2.23
c. Inservice coord. with local endeavors	2.22	2.11	1.93	2.50	2.33	1.67	1.40	1.80	2.02
d. Teacher centers	1.61	2.11	1.64	2.00	1.98	1.56	1.40	2.00	1.79
e. Improved teacher evaluation	2.15	2.45	2.14	2.08	1.98	1.63	1.60	2.60	2.09
f. Inservice on higher level sci. & math.	1.54	1.95	1.46	1.33	1.33	1.44	1.40	2.20	1.59
g. Extended year contracts	1.54	2.00	1.79	2.00	2.33	1.94	1.60	1.60	1.85
h. Academic year institutes	1.84	2.17	1.64	1.83	2.67	1.69	1.80	1.60	1.86
i. Late afternoon or evening institute classes	1.77	1.89	1.14	1.92	2.67	1.62	1.60	1.20	1.67
j. Inservice on teaching methods	1.47	1.56	1.64	1.25	2.34	1.31	1.60	1.20	1.48
k. Sabbatical leaves	1.23	1.65	1.93	2.33	1.98	1.88	2.00	2.20	1.83

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Table 7 (continued)

Interventions	Superin- tendents & Prin- cipals (13)	School Board Members (18)	Curriculum Directors & Super- visors (14)	Teachers (12)	Voca- tional Educators (3)	Higher Educa- tion Personnel (16)	CDE Staff (5)	Elected Officials (5)	Total (86)
3. Enhancing Teaching as a Career									
a. Increasing salaries for all teachers	2.07	1.94	2.14	2.67	1.50	2.56	2.00	2.60	2.24
b. Other incentives for teachers	2.24	2.28	2.07	2.33	2.00	2.28	2.60	1.80	2.23
c. Improved profes- sional environ.	1.76	2.28	2.07	2.50	1.50	1.75	1.40	2.40	2.03
d. Increasing salaries for sci. & math. teachers	1.54	1.65	1.85	2.33	2.50	2.38	1.80	2.20	1.97
e. Teacher recogni- tion	2.09	2.28	2.00	2.42	2.00	2.06	2.00	2.60	2.18
f. Performance pay	1.62	2.11	1.43	1.33	0.50	1.81	1.80	2.60	1.71
g. Collaborative research	1.24	1.59	1.43	2.20	1.00	1.31	2.00	2.00	1.57
h. Improving teacher recruit- ment	1.62	2.11	1.64	2.16	1.00	1.56	1.60	2.20	1.80
i. Reduced work loads	1.38	1.65	1.86	2.09	2.00	2.00	2.00	1.60	1.80
j. More emphasis on profess. growth	2.16	2.61	2.22	2.67	2.00	2.13	1.60	2.80	2.33

Table 7 (continued)

Interventions	Superintendents & Principals (13)	School Board Members (18)	Curriculum Directors & Supervisors (14)	Teachers (12)	Vocational Educators (3)	Higher Education Personnel (16)	CDE Staff (5)	Elected Officials (5)	Total (86)
4. Improved Instructional Practices									
a. Mastery learning	2.24	2.28	1.71	2.00	2.67	2.12	2.00	2.20	2.10
b. Improved student/teacher ratio	1.61	2.11	2.07	2.36	2.33	2.00	1.60	2.00	2.02
c. Computer-assisted instruction	2.01	2.11	1.79	1.45	2.33	1.56	1.40	2.00	1.81
5. Increased Student Requirements									
a. Increasing graduation require.	1.99	2.22	1.57	1.90	1.00	1.88	2.00	2.60	1.94
b. Increasing class time devoted to instruction	2.16	2.61	2.29	2.40	1.67	2.06	2.00	2.40	2.28
c. Increasing college admission requirements	1.77	2.39	2.00	2.30	1.00	1.81	2.00	2.60	2.05
d. Increasing homework	1.39	2.06	1.64	1.67	1.33	2.13	1.60	2.00	1.87
e. Increasing length of school day or year	1.62	1.61	1.00	0.90	1.33	1.63	1.40	2.20	1.43
f. Increasing school days devoted to instruction	2.07	2.22	1.79	1.60	1.33	1.94	2.00	2.20	1.95
g. Increasing academic req. for athletics	0.92	1.61	1.14	1.60	0.33	1.50	1.40	1.40	1.34

Table 7 (continued)

Interventions	Superin-tendents & Prin-cipals (13)	School Board Members (18)	Curriculum Directors & Super-visors (14)	Teachers (12)	Voca-tional Educators (3)	Higher Educa-tion Personnel (16)	CDE Staff (5)	Elected Officials (5)	Total (86)
6. <u>Improving School Curriculum</u>									
a. Developing more courses with applications	2.50	2.30	2.00	2.40	3.00	1.94	2.40	1.80	2.23
b. Improving program evaluation	2.23	2.47	2.36	2.10	2.67	1.81	1.80	1.80	2.17
c. Training for local districts on curr. dev. & implementation	1.69	2.18	1.64	1.60	2.34	1.50	1.40	1.60	1.74
d. Developing more rigorous courses	1.54	2.25	1.64	1.60	1.67	1.87	2.00	2.60	1.87
e. Developing model district curr. patterns	1.77	1.88	1.86	2.10	1.67	1.81	1.40	1.80	1.84
f. Reducing "frill" courses	1.23	2.44	1.72	1.90	1.65	2.06	1.80	2.60	1.94
g. Developing consortia	1.31	1.88	1.64	1.80	1.66	1.56	2.20	1.80	1.69
h. Federal funding of new curriculum project	1.31	1.53	1.43	2.20	1.67	1.38	1.40	1.20	1.52
i. New state standards for textbooks	0.85	1.12	1.14	1.10	1.33	1.50	1.00	1.00	1.14
j. Revising "old" NSF curricula	1.23	1.31	1.21	1.60	0.66	0.75	1.00	1.20	1.17

Table 7 (continued)

Interventions	Superintendents & Principals (13)	School Board Members (18)	Curriculum Directors & Supervisors (14)	Teachers (12)	Vocational Educators (3)	Higher Education Personnel (16)	CDE Staff (5)	Elected Officials (5)	Total (86)
7. Industrial Assistance									
a. Summer internships for teachers	2.09	2.33	2.07	2.27	3.00	2.06	2.00	2.40	2.20
b. Lecturers & workshop leaders	2.00	2.33	1.86	2.28	3.00	1.94	2.00	2.60	2.14
c. Seed money for projects	2.00	1.95	2.00	2.37	2.67	1.75	2.00	2.20	2.03
d. Part-time employment (e.g., summers)	1.92	1.94	1.79	2.28	2.67	1.81	1.60	2.20	1.96
e. Donating equip.	2.23	2.22	2.22	2.27	1.98	2.00	2.20	2.60	2.20
f. Assisting in evaluating curr.	2.23	1.94	1.21	1.64	2.33	1.31	1.40	2.40	1.63
g. Rotating employees into classroom teaching	1.39	1.78	1.97	1.50	2.33	0.89	1.60	2.60	1.60
h. Cash awards for professional development	1.54	1.45	1.36	1.90	1.66	1.44	1.80	2.60	1.60

Highly Effective = 3 Effective = 2 Slightly Effective = 1 Not Effective = 0 subgroups of educational leaders (e.g., principals or school board members), most of these variations "cancel each other out" and agreement on a precise course of action is not forthcoming. In such a context, action is often the result of fads or the views of individuals who are particularly influential politically. Thus, it must be expected that the process of arriving at good political decisions will be arduous. Extensive efforts will be necessary to bring to bear the results of cost-effectiveness analysis. The results of the political process, of course, should reflect legitimate political considerations and the specific contexts in which the actions will occur, but ideally the vagaries of the political process will not override the results of sound analysis.

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APPENDIX A. CALCULATING COST ESTIMATES

As indicated in the first chapter of this report, specialists in cost-effectiveness analysis regard the process of cost estimation as more of an art than a science. It is a process of making judgments about what costs will be involved in each case and making estimates of them based on the best information available. But they are estimates and should not be considered as precise as some of the figures below imply. A cost estimate of $0.55 per student should not be viewed as accurate to two significant figures; a more accurate way of expressing the meaning of this estimate would be as a confidence interval. An intuitive judgment is that instead of $0.55, it would be better to say something like, "We are 95 percent sure that the cost will be somewhat between $0.35 and $0.75 per student." This level of precision, of course, is not a problem for this type of analysis. The range of costs for the interventions is very large, and great precision is not needed for one to make comparisons of their costs in terms of their effectiveness.

In the tables which follow, cost estimates are provided (Table A.1) as well as the basis on which they were calculated (Table A.2). In the process there are several means of estimating which reappear at several points; some of these assumptions, procedures, and estimates will be described here because of their repeated use.

1. The useful life of remodeled facilities and new equipment was assumed to be ten years. Thus, costs for such items were prorated over that period of time.
2. Inservice education was assumed to have a useful life of five years. One basis for this somewhat arbitrary figure is the five-year period for which a teaching certificate is renewed, at least partially on the basis of credits accrued in the previous five years.
3. The average annual per pupil cost of education was assumed to be $3000.
4. The value of a person's discretionary time (outside of their regular working time) was assumed to be one-half of their standard wage, a common rule-of-thumb for this type of analysis.
5. A teacher's hourly rate of pay was based on an average salary of $21,500/year and calculated as follows: $21,500 ÷ 180 days ÷ 8 hours/day = $14.93/hour.
6. A supervisor's time was calculated on the basis of a $32,000 salary (an average of the salaries for different types of supervisors reported in <u>Certified Personnel: Salaries and Related Information</u>, Denver,CO: <u>Colorado Department of Education, Fall 1982</u>) plus an additional 50 percent for benefits, secretarial time, supplies, and other support for this position provided by the school district.
7. The cost of providing inservice education was estimated at $54 per credit hour which is the tuition fee charged by the University of Colorado Division of Continuing Education with the expectation that this fee will cover all the costs of a course.
8. The average salary increase for teachers as a result of taking credit courses and moving up the salary schedule was estimated to be $57 per semester hour. This figure was derived from data contained in <u>Colorado School Districts' Salary Schedules and Related Information, 1983</u>, <u>published by the Colorado Education Association</u>. The average was

obtained by using the data from the 12 largest school districts and an average number of years of experience of 12 years (the Colorado average).

9. Wages for student employment were assumed to be the federal minimum wage of $3.35.
10. The student-to-teacher ratio used is 18.6 students per teacher in a given class period as reported by the Colorado Department of Education _Status of K-12 Education_ report.
11. Given a six-period day and the data in #10 above, the number of students contacted by a secondary school teacher is 112 per day.
12. For college students, a full-time course load is assumed to be 15 semester credit hours per semester.

A third table, A.3, provides information on the calculations used to estimate the cost of the recommendations made in Chapter 5. It describes the _increase_ in the average annual per pupil cost of education at the local, state, and federal levels to implement these recommendations. More detail is provided in the explanatory notes which follow the table.

Table A.1

Costs of Single Interventions by Cost Category*
(Dollars per Science Student per Class per Year)

	Cost Category					
Intervention	S & L	F	T	EOC	P	Total
A. Objective #1: Quantity						
1. Increasing Student Requirements						
a. Increasing graduation requirements in science for all students	$30.02			$600.00		$630.00
b. Increasing college admission requirements in science for all incoming freshmen	30.02			600.00		630.00
c. Increasing the length of the school year by 4 weeks	333.40				$536.00	869.40
c'. Increasing the length of the school day by one period	500.00				401.99	901.99
d. Increasing the amount of homework assigned to students	1.59				100.50	102.09
e. Increasing proportion of total class time devoted to instruction	1.59					1.59
f. Increasing proportion of scheduled school days actually devoted to classes				60.00		60.00
g. Increasing academic requirements (grades) for student participation in athletics				301.50		301.50

*For definitions of cost categories, see Table 2 on page 30.

Table A.1 (continued)

Intervention	Cost Category S & L	F	T	EOC	P	Total
B. Objective #2: Quality						
1. Preservice Preparation of Teachers						
a. New standards for teacher preparation programs	$2.88		$8.96			$11.84
b. Greater science requirements for elementary school teachers	1.15		3.58			4.73
c. Specialized preparation programs for science teachers in grades 4-6	2.88		8.96			11.84
d. More courses emphasizing the applications of science	1.15	$0.05	3.58			4.78
e. More "hands-on" work as part of teacher education programs	1.86	0.24				2.10
f. Placing student teachers only with outstanding teachers	0.18		0.30			0.48
g. Stronger enforcement of the requirements that school districts hire only fully credentialed teachers						N/A
h. Loans or scholarships for persons preparing to be science teachers		11.39				11.39
2. Enhancing Teaching as a Career						
a. Increasing salary of teachers within all fields	161.29					161.29
b. Increasing salaries of teachers in science to be competitive with alternative employment	13.06					13.06

Table A.1 (continued)

Intervention	Cost Category S & L	F	T	EOC	P	Total
2. Enhancing Teaching as a Career (continued)						
c. Establish performance pay for teachers	$5.36					$5.36
d. Providing an improved professional environment within school districts						N/A
e. Initiating campaigns to enhance local teacher recognition and respect	0.08					0.08
f. Improving teacher recruitment and placement services	0.09					0.09
g. Involving teachers with researchers in collaborative educational research	5.35					5.35
h. More emphasis on professional growth, including better supervision and evaluation of teachers	5.36					5.36
i. Reduce workloads (i.e., fewer students/class + fewer classes/teacher)	240.00					240.00
3. Improving Instructional Practices						
a. Improved teacher-student ratio	240.00					240.00
b. Mastery learning	1.82		$0.27			2.09
c. Computer-assisted instruction						N/A

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Table A.1 (continued)

Intervention	Cost Category					
	S & L	F	T	EOC	P	Total
4. Inservice Education of Teachers						
a. Summer institutes for teachers	$1.53	$1.04	$0.09			$2.66
b. Academic year, full-time institute for science teachers	12.26	31.89	7.09			51.24
c. "Institute classes" conducted in late afternoon or evening during school year	1.53	0.65	0.27			2.45
d. Inservice education on the applications of science	1.82		0.27			2.09
e. Inservice education classes focused on more advanced levels of science	1.82		0.27			2.09
f. Inservice education classes on teaching methods	1.82		0.27			2.09
g. Inservice education program coordinated with local development endeavors	1.82		0.27			2.09
h. Teacher centers	2.11		0.27			2.38
i. Extended year contracts for program development	6.42					6.42
j. Improved teacher evaluation	3.58					3.58
k. Sabbatical leaves	23.12					23.12
5. Improving Science Materials, Equipment and Facilities	5.30					5.30

Table A.1 (continued)

Intervention	S & L	F	T	EOC	I	Total
6. Industrial Assistance						
a. Providing seed money for educational projects		$0.72			$1.07	$1.79
b. Providing cash awards		0.72			1.07	1.79
c. Equipment donations by industry		0.72			1.07	1.79
d. Business/industry loaning lectures/workshop leaders to schools		0.49			0.73	1.22
e. Rotating business and industrial employees to classroom teaching		30.46			45.70	76.16
f. Assistance in evaluating and developing curriculum		0.12			0.18	0.30
g. Providing industrial internships for the employment of teachers during summer		4.94			7.40	12.34
C. Objective #3: Appropriateness						
1. Improving the School Curriculum						
a. Developing more courses showing the applications of science for personal needs and addressing societal issues (local)	$0.59					0.59
a' Same as C.a. except federal		0.05				0.05
b. Developing more rigorous science courses for college-bound students (local)						0.59
b' Same as C.b. except federal						0.05

Table A.1 (continued)

Intervention	Cost Category S & L	F	T	EOC	P	Total
1. Improving the School Curriculum (continued)						
c. Reducing the number of "frill" courses						N/A
d. Federal funding of new curriculum development projects		$0.05				$0.05
e. Revising the "old" NSF curricula by expanding them or replacing portions with locally developed material	$0.30					0.30
f. Developing model curriculum patterns for districts						
g. Providing training for local school districts on how to develop and implement curricula	0.03					0.03
h. Establishing regional consortia of schools and universities to develop curricula	0.30					0.30
i. States (or groups of states) setting new standards for adopting texts	0.05					0.05
j. Developing model curriculum patterns for districts to consider	0.05					0.05
k. Improving program evaluation	0.03					0.03

Table A.1 (continued)

Intervention	Cost Category S & L	F	T	EOC	P	Total
D. Objective #4: Facilitation						
1. Improving Local Leadership						
a. Increasing the number of science supervisors within local school districts	$2.40					$2.40
b. Weighting program development and implementation more heavily in the job descriptions of local school district science supervisors	0.60					0.60
c. Weighting science program development and implementation more heavily in the job descriptions of general curriculum personnel	0.60					0.60
d. State or federal funding of local district plans for providing greater leadership in science education	3.50					3.50
e. Training for school board members with respect to science education	0.05					0.05
2. Testing Programs						
a. Conducting awareness conferences and training sessions in test preparation for district testing personnel	0.01					0.01
b. Developing banks of test items and making them available to local district personnel	0.02					0.02

Table A.1 (continued)

Intervention	S & L	F	T	EOC	P	Total
	Cost Category					
2. Testing Programs (continued)						
c. Holding an awareness conference for publishers of tests used in district-wide testing programs		$0.01				$0.01
d. Informing established citizen accountability committees in local school districts of the need for improved testing	$0.05					0.05
3. Public Education						
a. Various forms of media advertising to promote more science						N/A
b. Science television programs for the public						N/A
c. Adult education courses for the public on science and technology						N/A

Table A.2

Calculation of Costs for Single Interventions

Intervention	Cost Category	Explanation of Cost Calculations
A.a.	S & L	Based on interviews with school district administrators in two suburban Denver districts in which classrooms recently had been remodeled as science laboratories, the cost of such remodeling and purchase of equipment is estimated to be \$33,500. This cost is prorated over a 10-year period. The room is estimated to be used 6 periods per day for average-sized classes of 18.6 students: \$33,500 ÷ 10 years ÷ (18.6 x 6 students) = \$30.02/student/year.
	EOC	The educational opportunity cost to the student is the value of another course the student would no longer be able to take. It is valued at cost: \$3000/student/year ÷ 5 courses/year = \$600/student/year.
A.b.	S & L	Same as A.a. above.
	EOC	Same as A.a. above.
A.c.	S & L	\$3000/student/year ÷ 180 days x 20 days = \$333.40/student/4 weeks.
	P	Value of student time required for a longer school year and thus lost from possible summer employment: \$3.35/hour x 8-hour/workday x 20 days = \$536.00.
A.c.	S & L	Lengthening the school day by one class. Assume student now has 6 classes and then will have 7: \$3000 ÷ 6 = \$500/student/year.
	P	Value of student time required for a longer school day based on an increased length of 1 hour in class plus an additional 1/3 hour for homework. Assume student time is valued at 1/2 of what it could earn, i.e., 1/2 of minimum wage: 1 1/3 hours/day x 180 days x (3.35 ÷ 2) = \$401.99.

Table A.2 (continued)

ention	Cost Category	Explanation of Cost Calculations
	S & L	The cost of inservice education for teachers is assumed to be that of "full-cost" tuition for continuing education classes. It is prorated over a "useful life" of 5 years: 2 credit hours x $54/credit hours ÷ 112 students ÷ 5 years = $0.19/student/year.
		Teacher time for the inservice education is valued at its cost to the school district based on 180 eight-hour days for a year's salary ($21,500 ÷ 180 days ÷ 8 hours/day = $14.93/hour): 2 credit hours x 15 hours/credit x $14.93/hour ÷ 112 students ÷ 5 years = $0.80/student/year.
		Additional district supervision and help (1 day) based upon $48,000 for salary, benefits, support staff, and services: $48,000 ÷ 180 days ÷ 112 students ÷ 5 years = $0.60/student/year.
		Total S & L: $0.19 + $0.80 + $0.60 = $1.59.
	P	Assume an additional 20 minutes/day/student and that student time is valued at 1/2 of minimum wage: ($3.35/hour ÷ 2) x 1/3 hour/day x 180 days = $100.50/year.
	S & L	Same as S & L for A.d. above.
	EOC	Assume 2% of time valued at its cost of $3000 per student per year: .02 x $3000 = $60.
	EOC	Assume student will expend additional effort required for eligibility and that this time amounts to 1 hour per day of work outside of class: 180 days x 1 hour/day x ($3.35/hour ÷ 2) = $301.50.
	S & L	Based on an assumed increase of 1 semester. If tuition equals 25% of educational cost, then 75% is cost to state (tuition x 3, or $535 x 3 per semester): ($535 x 3)/semester ÷ 112 students ÷ 5 years = $2.88.

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Table A.2 (continued)

ention	Cost Category	Explanation of Cost Calculations
	T	The cost of education at a state institution is estimated to be $5500/year for tuition, living expenses, etc.: $2750/semester ÷ 112 students/year ÷ 5 years = $4.93.
		Lost earnings while attending additional semester of college: 4 months x 21 days x 8-hour/day x $3.35/hour ÷ 112 students ÷ 5 years = $4.03.
	S & L	Assume tuition is 25% of cost as in B.1.a. above and assuming that an additional 6 semester hours are required: $1605 x 6 hours/15 hours ÷ 112 students ÷ 5 years = $1.15.
	T	Additional educational cost is for 6 semester hours. Use same assumptions as in B.1.a. above: $2750 x 6 hours/15 hours ÷ 112 students ÷ 5 years = $1.97.
		Lost earnings are same as B.1.a. above multiplied by 6/15: $4.03 x 6/15 = $1.61.
		Total cost to teacher: $1.97 + $1.61 = $3.58.
	S & L	Same as B.1.a. above.
	T	Same as B.1.a. above.
	S & L	Assume 2 additional courses are required, then the analysis is the same as B.1.b. above.
	F	Assume NSF-funded development of materials for this purpose at $10,000,000/year and there are 41,000,000 students in U.S. schools (K-12): $10,000,000 ÷ 41,000,000 ÷ 5 years = $0.05.
	T	Same as B.1.b. above.

Table A.2 (continued)

vention	Cost Category	Explanation of Cost Calculations
.	S & L	It is assumed that additional instructor time costing $30,000 per year will be needed equivalent to an instructor for a 3-credit-hour course: $30,000 ÷ 5 courses/year ÷ 20 students/course ÷ 112 students ÷ 5 years = $1.86.
	F	Same as B.1.d. above.
.	S & L	Assume $100/student teacher for additional selection and supervision costs: $100 ÷ 112 students/year ÷ 5 years = $0.18.
	T	Additional travel for student teacher: 10 miles x 15 weeks x 5 days/week x $0.22/mile ÷ 112 students ÷ 5 years = $0.30.
.	N/A	
.	F	Assume cost of education ($3500/year x 4 years) is paid back over 10 years on an interest-free loan with the cost of interest for the government being 9%. Interest Cost: $22,000(1.09)^{10}$ - $22,000 = $30,081. $30,081/(1.09)^{10}$ = $12,707 (amount to be set aside now to pay for the total interest). $12,707 ÷ 112 students per term ÷ 10 years = $11.39.
.	S & L	Assume increase of $3000/year: $3000 ÷ 18.6 students = $161.29.
.	S & L	Assume 8.1% of teachers are science teachers and that salaries for them will be increased $3000/year: $3000 ÷ 18.6 students x .081 = $13.06.

Table A.2 (continued)

ention	Cost Category	Explanation of Cost Calculations
	S & L	Assume additional supervision of 1 supervisor at 1/4-time teachers: $48,000 ÷ 80 ÷ 112 students/teacher = $5.36. Inservice education for supervisor assuming average number of students/school is 664: 2 credit hours x $54/credit hour ÷ 664 ÷ 5 years = $0.03. Cost of supervisor time to attend inservice: 2 credit hours x 15 hours/credit hour x $21/hour ÷ 664 students ÷ 5 years = $0.19. Total S & L cost: $5.36 + $0.03 + $0.19 = $5.58.
.	N/A	
.	S & L	For management of the process, assume 1 month time for 1000 teachers and miscellaneous expenses of $5000: $48,000 ÷ 12 ÷ 1000 ÷ 112 = $0.04. $5000 ÷ 1000 ÷ 112 = $0.04. Total S & L: $0.04 + $0.04 = $0.08.
.	S & L	Assume $1000 per person hired and that 10% of staff are hired each year. This intervention would apply to all teachers: ($1000 x 10%/year) ÷ 10 years ÷ 112 students = $0.09.
.	S & L	40 hours/year x $14.93/hour ÷ 112 students = $5.35.
.	S & L	Same as B.2.c. above.
.	S & L	Same as B.3.a. below.

Table A.2 (continued)

ention	Cost Category	Explanation of Cost Calculations
	S & L	Reduce workload by 10%. Since most costs, such as teacher salaries and facilities are a function of class size, assume that 80% of costs are applicable and are directly proportional: $3000 x 0.80 x 0.10 = $240.
	S & L	Inservice education is priced at cost. Inservice education at the rate of "full-cost" tuition for a continuing education class (3 semester-hours-credit): (3 x $54) ÷ 112 students ÷ 5 years = $0.29.
		Increased salary from upward movement on salary schedule due to taking a credit course. It is a cost to the district and a benefit to the teacher: $57/semester hours x 3 hours ÷ 112 students = $1.53/year.
		Total S & L cost: $0.29 + $1.53 = $1.82.
	T	Cost to teacher because of time expended: 3 semester hours x 45 hours/credit x ($14.93/hour x 1/2) ÷ 112 students ÷ 5 years = $1.80.
		Net cost to teacher: $1.80 - $1.53 = $0.27.
	N/A	
	S & L	Increased teacher salaries from receiving academic credit (see B.3.b. above): $1.53.
	F	Cost of the institute based on $195/week: 3 weeks x $195/week ÷ 112 students ÷ 5 years = $1.04.
	T	Cost: time lost - increased salary from participation. Cost of time lost: 3 weeks x 40 hours x ($3.35 x 2) ÷ 112 students ÷ 5 years = $1.44.
		Net cost: $1.44 - $1.53 (see above) = -$0.09.

Table A.2 (continued)

ntion	Cost Category	Explanation of Cost Calculations
	S & L	Increased salary from moving up on salary schedule assuming 24 semester hours of academic credit are earned: 24 semester hours x \$57 ÷ 112 students = \$12.26.
	F	Institute cost: \$7000 ÷ 112 students ÷ 5 years = \$12.54.
		Assume stipend for teachers of \$300/week: \$300 x 36 weeks ÷ 112 students ÷ 5 years = \$19.35.
	T	Lost salary = salary - stipend: (\$21,500 - \$10,800) ÷ 112 students = \$19.17.
		Net cost = lost salary - salary increase: \$19.17 - \$12.26 = \$7.09.
	S & L	Increased salary (see B.3.b. above): \$1.53.
	F	Cost of institute at \$360 per semester class: \$360 ÷ 112 students ÷ 5 years = \$0.65.
	T	Increased salary - time lost = net cost. Time lost: 3 semester-hours x 45 hours/credit x (\$14.93 ÷ 2) ÷ 112 students ÷ 5 years = \$1.80.
		Net cost: \$1.80 - \$1.53 = \$0.27.
	S & L	Cost of class at rate of "full-cost" tuition: (\$54 x 3) ÷ 112 students ÷ 5 years = \$0.29.
		Total S & L cost: \$0.29 + \$1.53 (see B.3.b. above) = \$1.82.
	T	See B.4.c. above.

Table A.2 (continued)

...ention	Cost Category	Explanation of Cost Calculations
		Same as B.4.d. above.
		Same as B.4.d. above.
		Same as B.4.d. above.
.		Same as B.4.d. plus an S & L amount for materials and supplies ($0.29) equal to the cost of the inservice education, giving a total of $2.38.
.	S & L	Assume an annual salary of $21,500 plus benefits of 20% and a school year of 36 weeks. The intervention is assumed to be an extension of 1 week: $717/week ÷ 112 students = $6.42.
.		Same as B.2.c.
.	S & L	The cost of the sabbatical is assumed to be 1/2 the salary and benefits of the average teacher: ($21,500 x 1.20) ÷ 2 ÷ 112 students ÷ 5 years = $6.42.
	S & L	Assume expendable supplies of $2.50/year. Assume one-time purchase of equipment and printed materials of $14/student to be prorated over 5 years: $14 ÷ 5 years = $2.80. Total: $2.50 + $2.80 = $5.30.
a.	F	If corporate tax rate is 40%, then the federal government bears 40% of the cost of what industry donates. 40% of the industry figure given below equals $0.72.
	I	Assume $1000 per teacher prorated over 5 years: $1000 ÷ 112 students ÷ 5 years = $1.79. Tax benefits reduce this cost to 60% of this amount, or $1.07.
b.		Same as B.6.a. above.

Table A.2 (continued)

Intervention	Cost Category	Explanation of Cost Calculations
B.6.c.		Same as B.6.a. above.
B.6.d.	F	For reasons given in B.6.a. above, this amount is 40% of the total calculated in Cost Category I below: 40% of \$1.22 = \$0.49.
	I	Assume 1 day of a professional whose salary is \$30,000 and who works 220 days/year. This time benefits 112 students: \$30,000 ÷ 220 days ÷ 112 students = \$1.22. 60% of \$1.22 = \$0.73.
B.6.e.	F	The difference between a teacher's salary and an industrial employee's salary is borne by industry: (\$30,000 - \$21,500) ÷ 112 students = \$76.16. Because of tax benefits, 40% is borne by the federal government: \$76.16 x 0.40 = \$30.46.
	I	\$76.16 x 0.60 = \$45.70.
B.6.f.	F	Assume 1 week of industrial employee's time benefits 2000 students: \$30,000 ÷ 50 ÷ 2000 = \$0.30. Because of tax benefits, 40% is borne by the federal government: 0.40 x \$0.30 = \$0.12.
	I	0.60 x \$0.30 = \$0.18.
B.6.g.	F	Because of tax benefits, the federal cost is 40% of the figure calculated under Cost Category I below: 0.40 x \$12.34 = \$4.94.
	I	Assume that because of the short-term nature of the employment, their value to the employer is 75% of their teaching salary. Thus contribution is 25%: (\$21,500 x 10 weeks/39 weeks x 0.25) ÷ 112 = \$12.34. 0.60 x \$12.34 = \$7.40.

Table A.2 (continued)

Intervention	Cost Category	Explanation of Cost Calculations
C.a.	S & L	Local curriculum development is based on an assumption of an 80,000-student school district (only a large one probably is prepared to allocate the resources required) and a course for 6000 students developed at a cost of \$25,000 which has a life expectancy of 7 years: \$25,000 ÷ 6000 students ÷ 7 years = \$0.59.
C.a.'	F	Federal curriculum development is based on an estimate of \$2,000,000 to develop a course potentially usable by all students in the U.S. at a given grade level and having a life expectancy of 7 years.
C.b.		Same as C.a. and C.a.' above.
C.c.		Same as A.a. above.
C.d.		Same as C.a.' above.
C.e.	S & L	This cost is assumed to be 1/2 of the cost of a new locally developed course. Thus the cost is 1/2 of that calculated as an S & L cost in C.a. above.
C.g.	S & L	It is assumed that training will be provided for one leader from each of 181 school districts with the exception of the largest 20 which would have an average of 3 each, giving a total of 221. The scope of training is assumed to be equivalent to six semester hours of course work and is estimated to cost \$54, giving a total of approximately \$72,000. It is prorated over all students in one state (Colorado) and assumed to have a useful life of 5 years: \$72,000 ÷ 545,000 students ÷ 5 years = \$0.03.
C.h.	S & L	Assume that lower unit cost obtained by several districts working together is partially balanced by the cost of greater quality sought through a more expensive development cost. If total cost is doubled but it is spread among 4 times as many students, the unit cost will be 1/2 that described in C.a. above for local curriculum development: \$0.59 x 1/2 = \$0.30.

Table A.2 (continued)

Intervention	Cost Category	Explanation of Cost Calculations
C.i.	S & L	Assume a cost of $100,000 for developing new standards and that they apply to 2,000,000 students: $100,000 ÷ 2,000,000 students = $0.05.
C.j.	S & L	Similar to c.i. above. If done at the federal level, the costs could be somewhat lower per student but this reduction probably would be counterbalanced substantially by attempts to do higher quality development work.
C.k.	S & L	Assume $4000 for an every-5-year external audit of district with 25,000 students: $4000 ÷ 25,000 ÷ 5 years = $0.03.
D.1.a.	S & L	Assume 1 supervisor per 20,000 students now at a cost of $48,000 for salary, benefits, support staff, and services. Assume also that supervision is increased to 2 supervisors for 20,000 students: $48,000 ÷ 20,000 = $2.40.
D.1.b.	S & L	Assume an additional 25% of time devoted to this function in a situation where there is 1 supervisor per 20,000 students: $48,000 ÷ 20,000 students x 0.25 = $0.60.
D.1.c.	S & L	Same as D.1.b. above.
D.1.d.	S & L	Estimated to be $3.50 per student.
D.1.e.	S & L	Each of five regional meetings is expected to cost $2500 including travel expenses, honoraria for workshop leaders and materials. Costs of travel for participants is estimated at $10 per person (carpooling is assumed) for a total of 900 school board members. The addition of a lunch for each participant gives a total cost of $25,900: $25,900 ÷ 545,000 students = $0.05.

Table A.2 (continued)

Intervention	Cost Category	Explanation of Cost Calculations
D.2.a.	S & L	It is assumed that there are 20 districts with testing personnel on their staff and representing 50% of the students in an average-sized state (Colorado). The cost of the awareness conference is estimated at \$2900: \$2900 ÷ 272,000 students = \$0.01.
D.2.b.	S & L	The cost of developing items for an item bank is estimated to be \$100/item for 500 items for a total cost of \$50,000. Assume that the items are available for use by all students in the state and they have a useful life of 5 years: \$50,000 ÷ 545,000 students ÷ 5 years = \$0.02.
D.2.c.	F	Assume a cost of \$12,000 and a beneficial effect for all students in the nation: \$12,000 ÷ 41,000,000 < \$0.01.
D.2.d.		The cost of printing and distributing materials to 2900 committee members at \$2 each and \$2000 for developing the materials is \$7800. The cost of a conference for this same people is estimated to be \$20,000. The total cost is \$27,800 and is assumed to benefit all students in the state: \$27,800 ÷ 545,000 students = \$0.05.
D.3.a., b., and c.		A per pupil cost analysis for these three interventions has not been conducted. Some cost information is provided, however, as follows. A 30-second public service announcement is estimated to cost \$3600 to prepare, exclusive of the cost of broadcast time. The cost of science television programs are estimated to be \$400,000 per 30-minute program. Adult education classes are estimated to cost \$54/semester hour for each participant.

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Table A.3

Calculation of Increase in Average Annual Per Pupil Cost of Education to Initiate Project Recommendations (Dollars/Pupil/Year)

Intervention	Cost per Science Student per Class per Year	Increase in Average Annual Per Pupil Cost of Education		
		Local	State	Federal
State Actions				
Assistance to local districts	--		$0.23 (a)	
B.1.e.	$1.86		0.15 (b)	
C.1.g.	0.03		0.03	
C.1.h.	0.30		0.04 (c)	
C.1.i.	0.05		0.05	
D.1.e.	0.05		0.05	
D.2.a.	0.01		0.01	
D.2.b.	0.02		0.02	
D.2.d.	0.05		0.05	
State leadership	--		0.18 (d)	
Local Actions				
A.1.a.	30.02	$1.15 (e)		
A.1.d.	1.59	0.13 (f)		
A.1.e.	1.59	0.13 (f)		
B.2.d.	N/A	0.22 (g)		
B.2.f.	0.08	0.08		
B.2.g.	0.09	0.09		
B.2.i.	2.91	0.25 (h)		
B.3.b.	1.82	0.15 (i)		
Inservice education	--	-- (j)		
B.5.	5.30	0.43 (k)		
C.1.h.	0.30	0.04 (l)		
C.1.k.	0.03	0.03		
D.1.a.	2.40	0.60 (m)		
Selection of principals	--	0.07 (n)		
Federal Actions				
B.4.c.	0.65			$0.65
C.1.a.	0.59			0.24 (o)
C.1.h.	0.30			0.08 (p)
Research	--			0.29 (q)
D.2.c.	0.01			0.01
Funding of state programs	--			0.20
	(Totals)	**$3.37**	**$0.81**	**$1.47**

Explanatory Notes for Table A.3

a. Based on an estimate of a $125,000/year program: $125,000 ÷ 545,000 students = $0.23.
b. Based on 8.1% of teachers being science teachers: $1.86 x .081 = $0.15.
c. Costs are allocated to 80,000 students rather than the original 6,000.
d. Based on an estimate of $100,000 to provide state leadership: $100,000 ÷ 545 students = $0.18.
e. Based on an estimate that this increase will offset 1/2 of all graduating seniors each year: $30.02 ÷ 13 grades x 1/2 = $1.15.
f. This intervention is science teachers who constitute 8.1% of the teachers: $1.59 x .081 = $0.13.
g. Based on an estimated cost of $100 per science teacher and an estimate of 230 students per science teacher (18.6 students/teacher ÷ .081 science teachers/teachers) and 1/2 of the students in a district being secondary students: $100 ÷ 230 x 1/2 = $0.22.
h. Based on an estimate of 8.1% of teachers being science teachers: $2.91 x .081 = $0.25.
i. Based on an estimate of 8.1% of teachers being science teachers: $1.82 x .081 = $0.15.
j. Included in the cost of other interventions.
k. Based on an estimate of 8.1% of classes (teachers) being science teachers: $5.30 x .081 = $0.43.
l. Same as "c" above. Local support of curriculum development is needed as well as the state support.
m. Some costs of supervision, mostly building level, are included in other local interventions. Some additional central district supervision is included here--25% time for one person for each 20,000 students: $2.40 x .25 = $0.60.
n. It is estimated that one principal will be recruited for each 7,000 students each year at an increased cost of $500: $500 ÷ 7000 students = $0.07.
o. Based on an estimated five curriculum projects operating at a given time at $2,000,000 per year: $2,000,000 x 5 ÷ 41,000,000 students = $0.24.
p. Support of local curriculum level is assumed at a cost equal to the total of the local and federal shares listed above.
q. Based on an estimate of $12,000,000 per year: $12,000,000 ÷ 41,000,000 students = $0.29.
r. Federal support of state programs, and indirectly local programs, of science education improvement is estimated at $8,000,000 per year. It is assumed that this support will supplement not supplant the activities specifically listed as state or local actions: $8,000,000 ÷ 41,000,000 students = $0.20.